# A

# PLAIN METHOD

## OF FINDING

## The DISTANCES of all the PLANETS from the SUN,

## BY THE

## Tranſit of VENUS over the SUN's DISC, in the Year 1761.

To which is ſubjoined,

An Account of Mr. HORROX's Obſervations of the TRANSIT of VENUS in the Year 1639.

AND ALSO,

Of the DISTANCES of all the PLANETS from the SUN, as deduced from OBSERVATIONS of the TRANSIT in the Year 1761.

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Fig. 1.

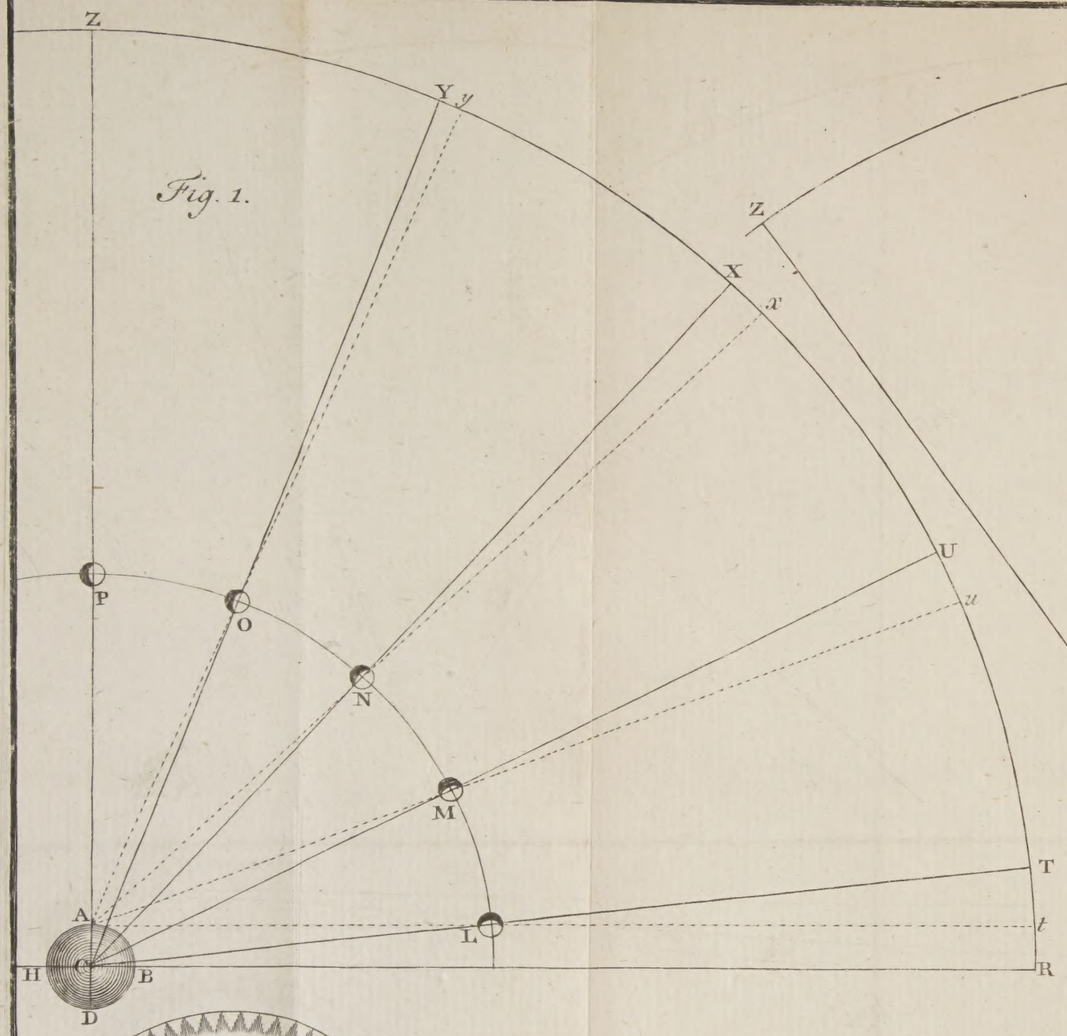



Fig. 2.

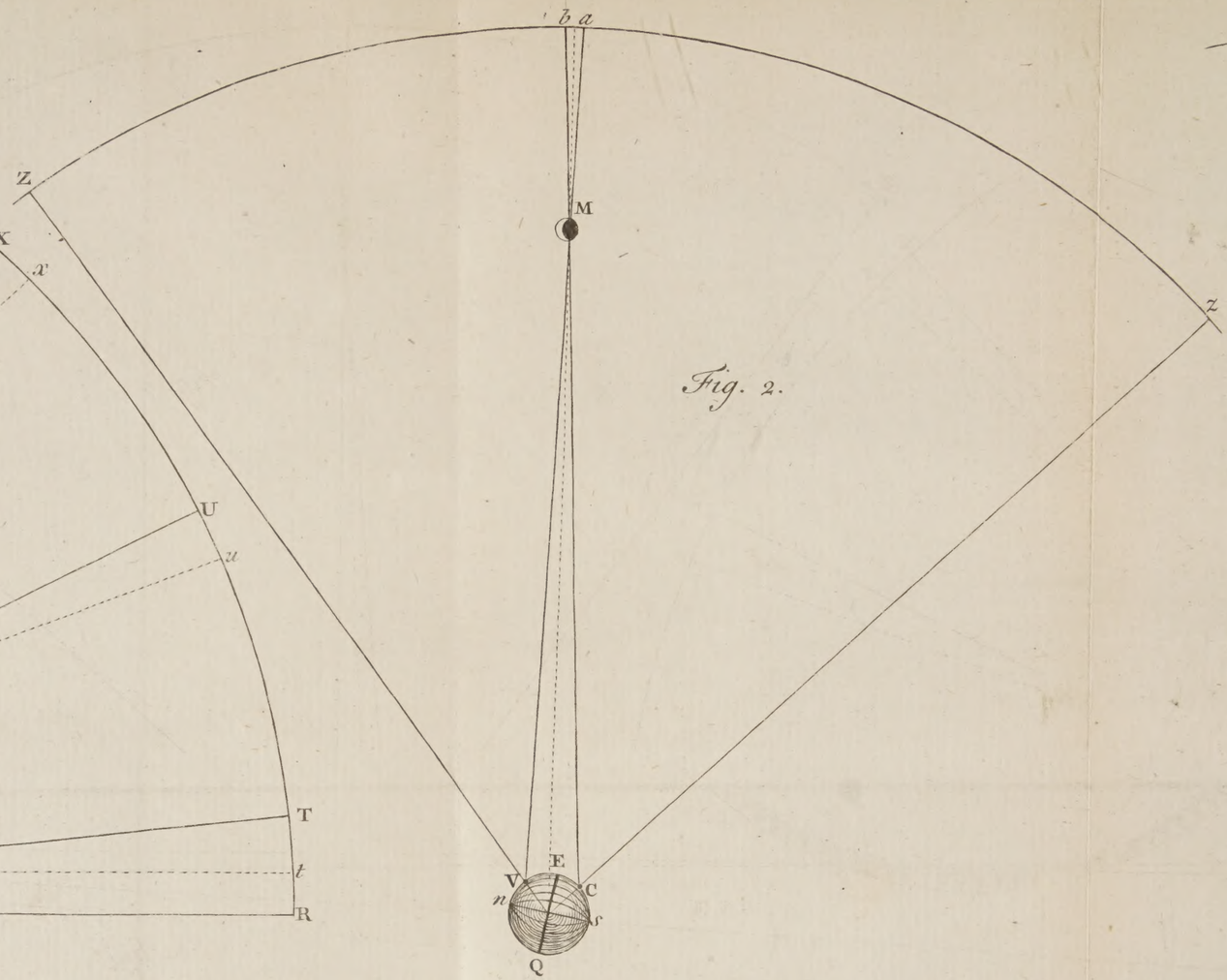



Fig. 5.

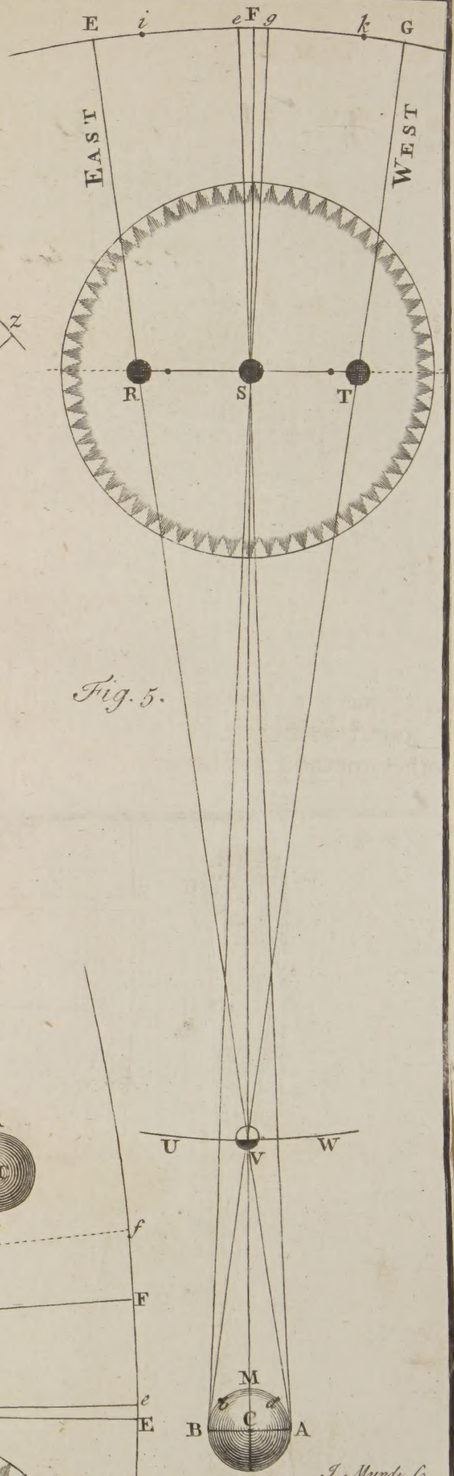



Fig. 3.

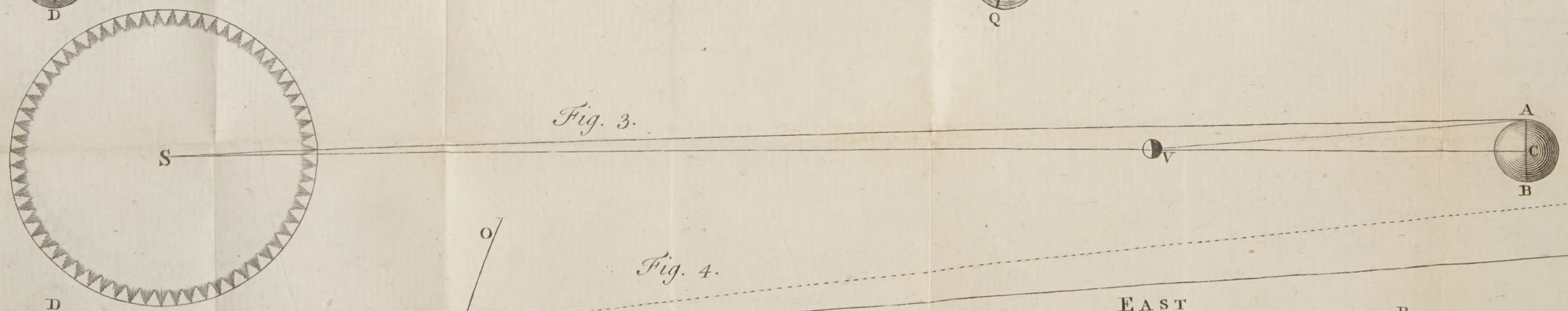
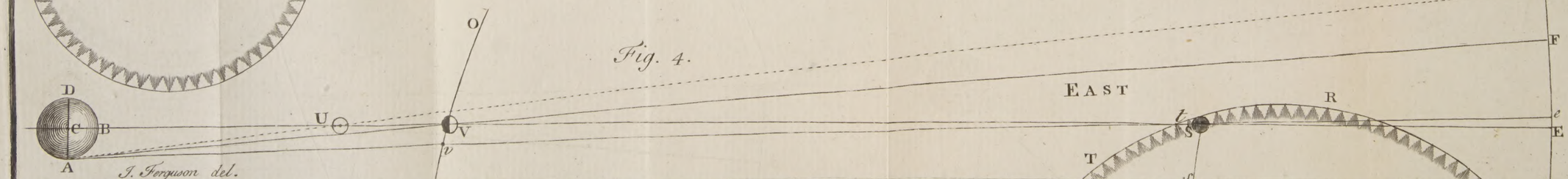



Fig. 4.







J. Ferguson del.

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# THE METHOD OF FINDING The DISTANCES of the PLANETS from the SUN.

## CHAPTER XXIII.

### ARTICLE I.

*Concerning parallaxes, and their uſe in general.*

1. THE * approaching tranſit of Venus over the Sun has juſtly engaged the attention of Aſtronomers, as it is a phenomenon ſeldom ſeen, and as the parallaxes of the Sun and planets, and their diſtances from one another, may be found with greater accuracy by it, than by any other method yet known.

2. The parallax of the Sun, Moon, or any planet, is the diſtance between it's true and apparent place in the heaven.—The true place of any celeſtial object, referred to the ſtarry heaven, is that in which it would appear if ſeen from the center of the Earth; the apparent place, is that in which it appears as ſeen from the Earth's ſurface.

To explain this, let *ABDH* be the Earth (Fig. 1. of Plate XIV.) *C* it's center, *M* the Moon, and *ZXR* an arc of the ſtarry heaven. To an obſerver at *C* (ſuppoſing the Earth to be tranſparent) the Moon *M* will appear at *U*, which is her true place

* The whole of this Diſſertation was publiſhed in the beginning of the year 1761, before the time of the Tranſit, except the 7th and 8th Articles, which are added ſince that time.

referred to the ſtarry firmament: but at the ſame inſtant, to an obſerver at *A* ſhe will appear at *u*, below her true place as among the ſtars. The angle *AMC* is called the Moon's parallax, and is equal to the oppoſite angle *UMu*, whoſe meaſure is the celeſtial arc *Uu*.—The whole Earth is but a point if compared with it's diſtance from the fixed ſtars, and therefore we conſider the ſtars as having no parallax at all.

3. The nearer the object is to the horizon, the greater is it's parallax; the nearer it is to the zenith, the leſs. In the horizon it is greateſt of all, in the zenith it is nothing.—Thus let *ALt* be the ſenſible horizon of an obſerver at *A*; to him the Moon at *L* is in the horizon, and her parallax is the angle *ALC*, under which the Earth's ſemidiameter *AC* appears as ſeen from her. This angle is called the Moon's horizontal parallax, and is equal to the oppoſite angle *TLt*, whoſe meaſure is the arc *Tt* in the ſtarry heaven. As the Moon riſes higher and higher to the points *M*, *N*, *O*, *P* in her diurnal courſe, the parallactic angles *UMu*, *XNx*, *YOy* diminiſh, and ſo do the arcs *Uu*, *Xx*, *Yy*, which are their meaſures, until the Moon comes to *P*; and then ſhe appears in the zenith *Z* without any parallax, her place being the ſame as ſeen from *A* on the Earth's ſurface, and from *C* it's center.

4. If the obſerver at *A* could take the true meaſure or quantity of the parallactic angle *ALC*, he might thereby find the Moon's diſtance from the center of the Earth. For then, in the plain triangle *LAC*, the ſide *AC*, which is the Earth's ſemidiameter, the angle *ALC*, which is the Moon's horizontal parallax, and the right angle *CAL*, would be given. Therefore, by trigonometry, As the tangent of the parallactic angle *ALC* is to radius, ſo is the Earth's ſemidiameter *AC* to the Moon's diſtance *CL* from the Earth's center *C*.—But becauſe we conſider the Earth's ſemidiameter as unity, and the logarithm of unity is nothing, ſubtract

tract the logarithmic tangent of the angle *ALC* from radius, and the remainder will be the logarithm of *CL*, whose number is equal to the number of semidiameters of the Earth by which the Moon is distant from the Earth's center.—Thus supposing the angle *ALC* of the Moon's horizontal parallax to be 57′ 18″.

| | |
|---|---|
| From the radius — — — | 10.0000000 |
| Subtract the tangent of 57′ 18″ | 8.2219207 |
| And there will remain — — | 1.7780793; |

which is the logarithm of 59.9955, the number of semidiameters of the Earth which are equal to the Moon's distance from the Earth's center. Then, 59.9955 being multiplied by 3985, the number of miles contained in the Earth's semidiameter, will give 239,082 miles for the Moon's distance from the center of the Earth.

5. But the true quantity of the Moon's horizontal parallax cannot be accurately determined by observing the Moon in the horizon, on account of the inconstancy of the horizontal refractions, which always vary according to the state of the atmosphere; and, at a mean rate, elevate the Moon's apparent place near the horizon half as much more than as her parallax depresseth it. And therefore, to have her parallax more accurate, Astronomers have thought of the following method, which seems to be a very good one, but hath not yet been put in practice.

Let two observers be placed under the same meridian, one in the northern hemisphere, and the other in the southern, at such a distance from each other, that the arc of the celestial meridian included between their two zeniths may be at least 80 or 90 degrees. Let each observer take the distance of the Moon's center from his zenith, by means of an exceeding good instrument, at the moment of her passing the meridian: add these two zenith-distances of the Moon together, and

their exceſs above the diſtance between the two zeniths will be the diſtance between the two apparent places of the Moon. Then, as the ſum of the natural ſines of the two zenith-diſtances of the Moon is to radius, ſo is the diſtance between her two apparent places to her horizontal parallax: which being found, her diſtance from the Earth's center may be found by the analogy mentioned in § 4.

Thus, in Fig. 2. let *V E C Q* be the Earth, *M* the Moon, and *Z b a z* an arc of the celeſtial meridian. Let *V* be *Vienna*, whoſe latitude *E V* is 48° 20′ north; and *C* the *Cape of Good Hope*, whoſe latitude *E C* is 34° 30′ ſouth: both which latitudes we ſuppoſe to be accurately determined before-hand by the obſervers. As theſe two places are on the ſame meridian *n V E C s*, and in different hemiſpheres, the ſum of their latitudes 82° 50′ is their diſtance from each other. *Z* is the zenith of *Vienna*, and *z* the zenith of the *Cape of Good Hope*; which two zeniths are alſo 82° 50′ diſtant from each other, in the common celeſtial meridian *Z z*. To the obſerver at *Vienna*, the Moon's center will appear at *a* in the celeſtial meridian; and at the ſame inſtant, to the obſerver at the *Cape*, it will appear at *b*. Now ſuppoſe the Moon's diſtance *Z a* from the zenith of *Vienna* to be 38° 1′ 53″; and her diſtance *z b* from the zenith of the *Cape of Good Hope* to be 46° 4′ 41″: the ſum of theſe two zenith-diſtances *(Z a + z b)* is 84° 6′ 34″, from which ſubtract 82° 50″, the diſtance *Z z* between the zeniths of theſe two places, and there will remain 1° 16′ 34″ for the arc *b a*, or diſtance between the two apparent places of the Moon's center, as ſeen from *V* and from *C*. Then, ſuppoſing the tabular radius to be 10000000, the natural ſine of 38° 1′ 53″ (the arc *Z a)* is 6160816, and the natural ſine of 46° 4′ 41″ (the arc *z b)* is 7202821: the ſum of both theſe ſines is 13363637. Say therefore, As 13363637

is to 10000000, ſo is 1° 16′ 34″, to 57′ 18″, which is the Moon's horizontal parallax.

If the two places of obſervation be not exactly under the ſame meridian, their difference of longitude muſt be accurately taken, that proper allowance may be made for the Moon's declination whilſt ſhe is paſſing from the meridian of the one to the meridian of the other.

6. The Earth's diameter, as ſeen from the Moon, ſubtends an angle of double the Moon's horizontal parallax; which being ſuppoſed (as above) to be 57′ 18″, or 3438″, the Earth's diameter muſt be 1° 54′ 36″, or 6876″. When the Moon's horizontal parallax (which is variable on account of the excentricity of her orbit) is 57′ 18″, her diameter ſubtends an angle 31′ 2″, or 1862″: therefore, the Earth's diameter is to the Moon's diameter, as 6876 is to 1862; that is, as 3.69 is to 1.

And ſince the relative bulks of ſpherical bodies are as the cubes of their diameters, the Earth's bulk is to the Moon's bulk, as 49.4 is to 1.

7. The parallax, and conſequently the diſtance and bulk, of any primary planet, might be found in the above manner, if the planet was near enough to the Earth, ſo as to make the difference of it's two apparent places ſufficiently ſenſible: but the neareſt planet is too remote for the accuracy required. In order therefore to determine the diſtances and relative bulks of the planets with any tolerable degree of preciſion, we muſt have recourſe to a method leſs liable to error: and this, the approaching tranſit of Venus over the Sun's diſc will afford us.

8. From the time of any inferior conjunction of the Sun and Venus to the next, is 583 days 22 hours 7 minutes. And, if the plane of Venus's orbit were coincident with the plane of the ecliptic, ſhe would paſs directly between the Earth and the Sun at each inferior conjunction, and would then appear like a dark round ſpot on the Sun for about

7 hours

7 hours and 3 quarters. But Venus's orbit (like the Moon's) only intersects the ecliptic in two opposite points, called it's Nodes. And therefore one half of it is on the north side of the ecliptic, and the other on the south: on which account, Venus can never be seen on the Sun, but at those inferior conjunctions which happen in or near the nodes of her orbit. At all the other conjunctions, she either passes above or below the Sun; and her dark side being then towards the Earth, she is invisible. —The last time when this planet was seen like a spot on the Sun, was on the 24th of *November* Old Stile, in the year 1639.

## ARTICLE II.

*Shewing how to find the horizontal parallax of Venus by observation, and from thence, by analogy, the parallax and distance of the Sun, and of all the Planets from him.*

9. In Fig. 4. of Plate XIV. let *D B A* be the Earth, *V* Venus, and *T S R* the eastern limb of the Sun. To an observer at *B*, the point *t* of that limb will be on the meridian, it's place referred to the heaven will be at *E*, and Venus will appear just within it at *S*. But, at the same instant, to an observer at *A*, Venus is east of the Sun, in the right line *AVF*; the point *t* of the Sun's limb appears at *e* in the heaven, and if Venus were then visible, she would appear at *F*. The angle *CVA* is the horizontal parallax of Venus, which we seek; and is equal to the opposite angle *FVE*, whose measure is the arc *FE*. *ASC* is the Sun's horizontal parallax, equal to the opposite angle *eSE*, whose measure is the arc *eE*: and *FAe* (the same as *VAv*) is Venus's horizontal parallax from the Sun, which may be found by observing how much later in absolute time her total ingress on the Sun is, as seen from *A*, than as seen from *B*, which is the time

time ſhe takes to move from *V* to *v* in her orbit *O V v*.

10. It appears by the tables of Venus's motion and the Sun's, that at the time of her enſuing tranſit, ſhe will move 4′ of a degree on the Sun's diſc in 60 minutes of time; and therefore ſhe will move 4″ of a degree in one minute of time.

Now, let us ſuppoſe, that *A* is 90° weſt of *B*, ſo that when it is noon at *B*, it will be VI in the morning at *A*; that the total ingreſs as ſeen from *B* is at 1 minute paſt XII. but that as ſeen from *A* it is at 7 minutes 30 ſeconds paſt VI: deduct 6 hours for the difference of meridians of *A* and *B*, and the remainder will be 6 minutes 30 ſeconds for the time by which the total ingreſs of Venus on the Sun at *S* is later as ſeen from *A* than as ſeen from *B*: which time being converted into parts of a degree is 26″, or the arc *F e* of Venus's horizontal parallax from the Sun: for, as 1 minute of time is to 4 ſeconds of a degree, ſo is 6½ minutes of time to 26 ſeconds of a degree.

11. The times in which the planets perform their annual revolutions about the Sun, are already known by obſervation.—From theſe times, and the univerſal power of gravity by which the planets are retained in their orbits, it is demonſtrable, that if the Earth's mean diſtance from the Sun be divided into 100000 equal parts, Mercury's mean diſtance from the Sun muſt be equal to 38710 of theſe parts—Venus's mean diſtance from the Sun, to 72333—Mars's mean diſtance, 152369—Jupiter's 520096—and Saturn's, 954006. Therefore, when the number of miles contained in the mean diſtance of any planet from the Sun is known, we we can, by theſe proportions, find the mean diſtance in miles of all the reſt.

12. At the time of the enſuing tranſit, the Earth's diſtance from the Sun will be 1015 (the mean diſtance being here conſidered as 1000) and Venus's diſtance from the Sun will be 726 (the

mean

mean diſtance being conſidered as 723) which differences from the mean diſtances ariſe from the elliptical figure of the planets orbits.—Subtract 726 parts from 1015, and there will remain 289 parts for Venus's diſtance from the Earth at that time.

13. Now, ſince the horizontal parallaxes of the planets are * inverſely as their diſtances from the Earth's center, it is plain, that as Venus will be between the Earth and the Sun on the day of her tranſit, and conſequently her parallax will be then greater than the Sun's, if her horizontal parallax can be then aſcertained by obſervation, the Sun's horizontal parallax may be found, and conſequently his diſtance from the Earth.—Thus, ſuppoſe Venus's horizontal parallax ſhould be found to be $36''.3480$; then, As the Sun's diſtance 1015 is to Venus's diſtance 289, ſo is Venus's horizontal parallax $36''.3480$ to the Sun's horizontal parallax $10''.3493$ on the day of her tranſit. And the difference of theſe two parallaxes, viz. $25''.9987$ (which may be eſteemed $26''$) will be the quantity of Venus's horizontal parallax from the Sun; which is one of the elements for projecting or delineating her tranſit over the Sun's diſc, as will appear further on.

To find the Sun's horizontal parallax at the time of his mean diſtance from the Earth, ſay, As 1000 parts, the Sun's mean diſtance from the Earth's center, is to 1015, his diſtance therefrom on the

* To prove this, let $S$ be the Sun (Fig. 3.) $V$ Venus, $AB$ the Earth, $C$ it's center, and $AC$ it's ſemidiameter. The angle $AVC$ is the horizontal parallax of Venus, and $ASC$ the horizontal parallax of the Sun. But by the property of plain triangles, as the ſine of $AVC$ (or of $SVA$ it's ſuppliment to 180°) is to the ſine of $ASC$, ſo is $AS$ to $AV$, and ſo is $CS$ to $CV$.—*N. B.* In all angles leſs than a minute of a degree, the ſines, tangents, and arcs, are ſo nearly equal, that they may without error be uſed for one another. And here we make uſe of *Gardiner*'s logarithmic tables, becauſe they have the ſines to every ſecond of a degree.

day

day of the tranſit, ſo is 10″.3493, his horizontal parallax on that day, to 10″.5045, his horizontal parallax at the time of his mean diſtance from the Earth's center.

14. The Sun's parallax being thus (or any other way ſuppoſed to be) found, at the time of his mean diſtance from the Earth, we may find his true diſtance therefrom, in ſemidiameters of the Earth, by the following analogy. As the ſine (or tangent of ſo ſmall an arc as that) of the Sun's parallax 10″.5045 is to radius, ſo is unity or the Earth's ſemidiameter to the number of ſemidiameters of the Earth that the Sun is diſtant from it's center, which number, being multiplied by 3985, the number of miles contained in the Earth's ſemidiameter, will give the number of miles by which the Sun is diſtant from the Earth's center.

Then, by § 11, As 100000, the Earth's mean diſtance from the Sun in parts, is to 38710, Mercury's mean diſtance from the Sun in parts, ſo is the Earth's mean diſtance from the Sun in miles to Mercury's mean diſtance from the Sun in miles.—And,

As 100000 is to 72333, ſo is the Earth's mean diſtance from the Sun in miles to Venus's mean diſtance from the Sun in miles.—Likewiſe,

As 100000 is to 152369, ſo is the Earth's mean diſtance from the Sun in miles to Mars's mean diſtance from the Sun in miles.—Again,

As 100000 is to 520096, ſo is the Earth's mean diſtance from the Sun in miles to Jupiter's mean diſtance from the Sun in miles.—Laſtly,

As 100000 is to 954006, ſo is the Earth's mean diſtance from the Sun in miles to Saturn's mean diſtance from the Sun in miles.

And thus, by having found the diſtance of any one of the planets from the Sun, we have ſufficient *data* for finding the diſtances of all the reſt.—And then, from their apparent diameters at theſe known diſtances,

diſtances, their real diameters and bulks may be found.

15. The Earth's diameter, as ſeen from the Sun, ſubtends an angle of double the Sun's horizontal parallax, at the time of the Earth's mean diſtance from the Sun: and the Sun's diameter, as ſeen from the Earth at that time, ſubtends an angle of $32' 2''$, or $1922''$. Therefore, the Sun's diameter is to the Earth's diameter, as 1922 is to 21.—And ſince the relative bulks of ſpherical bodies are as the cubes of their diameters, the Sun's bulk is to the Earth's bulk, as 756058 is to 1; ſuppoſing the Sun's mean horizontal parallax to be $10''.50$, as above.

16. It is plain by Fig. 4. that whether Venus be at *U* or *V*, or in any other part of the right line *B V S*, it will make no difference in the time of her total ingreſs on the Sun at *S*, as ſeen from *B*; but as ſeen from *A* it will. For, if Venus be at *V*, her horizontal parallax from the Sun is the arc *Fe*, which meaſures the angle *F A e*: but if ſhe be nearer the Earth, as at *U*, her horizontal parallax from the Sun is the arc *f e*, which meaſures the angle *f A e*; and this angle is greater than the angle *F A e*, by the difference of their meaſures *f F*. So that, as the diſtance of the celeſtial object from the Earth is leſs, it's parallax is the greater.

17. To find the parallax of Venus by the above method, it is neceſſary, 1. That the difference of meridians of the two places of obſervation be 90°.—2. That the time of Venus's total ingreſs on the Sun be when his eaſtern limb is either on the meridian of one of the places, or very near it.—And, 3. That each obſerver has his clock exactly regulated to the equal time at his place. But as it might perhaps be difficult to find two places on the Earth ſuited to the firſt and ſecond of theſe requiſites, we ſhall ſhew how this important problem may be ſolved by a ſingle obſerver, if he be exact

as

as to his longitude, and has his clock truly adjuſted to the equal time at his place.

18. That part of Venus's orbit in which ſhe will move during her tranſit on the Sun, may be conſidered as a ſtraight line; and therefore, a plane may be conceived to paſs both through it and the Earth's center. To every place on the Earth's ſurface cut by this plane, Venus will be ſeen on the Sun in the ſame path that ſhe would deſcribe as ſeen from the Earth's center: and therefore, ſhe will have no parallax of latitude, either north or ſouth; but will have a greater or leſs parallax of longitude, as ſhe is more or leſs diſtant from the meridian, at any time during her tranſit.

*Matura*, a town and fort on the ſouth coaſt of the iſland of *Ceylon*, will be in this plane at the time of Venus's total ingreſs on the Sun; and the Sun will then be $62°\frac{1}{2}$ eaſt of the meridian of that place. Conſequently, to an obſerver at *Matura*, Venus will have a conſiderable parallax of longitude eaſtward from the Sun, when ſhe would appear to touch the Sun's eaſtern limb, as ſeen from the Earth's center, at which the Aſtronomical tables ſuppoſe the obſerver to be placed, and give the times as ſeen from thence.

19. According to theſe tables, Venus's total ingreſs on the Sun will be 50 minutes after VII in the morning, at *Matura* *, ſuppoſing that place to be 80° eaſt longitude from the meridian of *London*; which is the obſerver's buſineſs to determine. Let us imagine that he finds it to be exactly ſo, but that to him the total ingreſs is at VII hours 55 minutes 46 ſeconds, which is 5 minutes 46 ſeconds later than the true calculated time of total ingreſs, as ſeen from the Earth's center. Then, as Venus's

* The time of total ingreſs at *London*, as ſeen from the Earth's center, is at 30 minutes after II in the morning; and if *Matura* be juſt 80° (or 5 hours 20 minutes) eaſt of *London*, when it is 30 minutes paſt II in the morning at *London*, it is 50 minutes paſt VII at *Matura*.

motion

motion on (or towards, or from) the Sun is at the rate of 4 minutes of a degree in an hour (by § 10.) her motion muſt be 23″.1 of a degree in 5 minutes 46 ſeconds of time: and this 23″.1 is her parallax eaſtward, from her total ingreſs as ſeen from *Matura*, when her ingreſs would be total if ſeen from the Earth's center.

20. At VII hours 50 minutes in the morning, the Sun is 62°½ from the meridian; at VI in the morning he is 90° from it: therefore, as the ſine of 62°½ is to the ſine of 23″.1 (which is Venus's parallax from her true place on the Sun at VII hours 50 minutes) ſo is radius, or the ſine of 90°, to the ſine of 26″, which is Venus's horizontal parallax from the Sun at VI. In logarithms thus:

| | |
|---|---|
| As the logarithmic ſine of 62° 30′ - - - | 9.9479289 |
| Is to the logarithmic ſine of 23″.1 - - - | 6.0481510 |
| So is the logarithmic radius - - - - - - | 10.0000000 |
| To the logarithmic ſine of 26″ very nearly | 6.1002221 |

Divide the Sun's diſtance from the Earth, 1015, by his diſtance from Venus 726 (§ 12.) and the quotient will be 1.3980; which being multiplied by Venus's horizontal parallax from the Sun 26″, will give 36″.3480 for her horizontal parallax as ſeen from the Earth at that time.—Then (by § 13.) As the Sun's diſtance 1015 is to Venus's diſtance 289, ſo is Venus's horizontal parallax 36″.3480 to the Sun's horizontal parallax 10″.3493.—If Venus's horizontal parallax from the Sun is found by obſervation to be greater or leſs than 26″, the Sun's horizontal parallax muſt be greater or leſs than 10″.3493 accordingly.

21. And thus, by a ſingle obſervation, the parallax of Venus, and conſequently the parallax of the Sun, might be found, if we were ſure that the Aſtronomical tables were quite correct as to the time of Venus's total ingreſs on the Sun.—But although the tables may be ſafely depended upon for

for ſhewing the true duration of the tranſit, which will not be quite 6 hours from the time of Venus's total ingreſs on the Sun's eaſtern limb, to the beginning of her egreſs from his weſtern; yet they may perhaps not give the true times of theſe two internal contacts: like a good common clock, which though it may be truſted to for meaſuring a few hours of time, yet perhaps it may not be quite adjuſted to the meridian of the place, and conſequently not true as to any one hour; which every one knows is generally the caſe.—Therefore, to make ſure work, the obſerver ought to watch both the moment of Venus's total ingreſs on the Sun, and her beginning of egreſs from him, ſo as to note preciſely the time between theſe two inſtants, by means of a good clock: and by comparing the interval at his place with the true calculated interval as ſeen from the Earth's center, which will be 5 hours 58 minutes, he may find the parallax of Venus from the Sun both at her total ingreſs and beginning of egreſs.

22. The manner of obſerving the tranſit ſhould be as follows.—The obſerver being provided with a good teleſcope, and a pendulum clock well adjuſted to the mean diurnal revolution of the Sun, and as near to the time at his place as conveniently may be; and having an aſſiſtant to watch the clock at the proper times, he muſt begin to obſerve the Sun's eaſtern limb through his teleſcope, twenty minutes at leaſt before the computed time of Venus's total ingreſs upon it, leſt there ſhould be an error in the time thereof as given by the tables.

When he perceives a dent (as it were) to be made in the Sun's limb by the interpoſition of the dark body of Venus, he muſt then continue to watch her through the teleſcope as the dent increaſes; and his aſſiſtant muſt watch the time ſhewn by the clock, till the whole body of the planet appears juſt within the Sun's limb: and the moment when the bright limb of the Sun appears

cloſe by the eaſt ſide of the dark limb of the planet, the obſerver, having a little hammer in his hand, is to ſtrike a blow therewith on the table or wall; the moment of which, the aſſiſtant notes by the clock, and writes it down.

Then, let the planet paſs on for about 2 hours 59 minutes, in which time it will be got to the middle of it's apparent path on the Sun, and conſequently will then be at it's leaſt apparent diſtance from the Sun's center; at which time, the obſerver muſt take it's diſtance from the Sun's center, by means of a good micrometer, in order to aſcertain it's true latitude or declination from the ecliptic, and thereby find the places of it's nodes.

This done, there is but little occaſion to obſerve it any longer, until it comes ſo near the Sun's weſtern limb, as almoſt to touch it. Then the obſerver watches the planet carefully with his teleſcope; and his aſſiſtant watches the clock, ſo as to note the preciſe moment of the planet's touching the Sun's limb, which the aſſiſtant knows by the obſerver's ſtriking a blow with his hammer.

23. The aſſiſtant muſt be very careful in obſerving what minute on the Dial-Plate the minute-hand has paſt, when he has obſerved the ſecond-hand at the inſtant the blow was ſtruck by the hammer: otherwiſe, though he be right as to the number of ſeconds of the current minute, he may be apt to make a miſtake in the number of minutes.

24. To thoſe places where the tranſit begins before XII at noon, and ends after it, Venus will have an eaſtern parallax from the Sun at the beginning, and a weſtern parallax from the Sun at the end; which will contract the duration of the tranſit, by cauſing it to begin later, and end ſooner at theſe places, than it does as ſeen from the Earth's center; which may be explained in the following manner.

In

In Fig. 5. of Plate XIV. let *B MA* be the Earth, *V* Venus, and *S* the Sun. The Earth's motion on it's axis from weſt to eaſt, or in the direction *AMB*, carries an obſerver on that ſide contrary to the motion of Venus in her orbit, which is in the direction *UVW*, and will therefore cauſe her motion to appear quicker on the Sun's diſc, than it would appear to an obſerver placed at the Earth's center *C*, or at either of it's poles. For, if Venus were to ſtand ſtill in her orbit at *V* for twelve hours, the obſerver on the Earth's ſurface would in that time be carried from *A* to *B*, through the arc *AMB*. When he was at *A*, he would ſee Venus on the Sun at *R*; when at *M*, he would ſee her at *S*; and when he was at *B*, he would ſee her at *T*: ſo that his own motion would cauſe the planet to appear in motion on the Sun through the line *RST*: which being in the direction of her apparent motion on the Sun as ſhe moves in her orbit *UW*, her motion will be accelerated on the Sun to this obſerver, juſt as much as his own motion would ſhift her apparent place on the Sun, if ſhe were at reſt in her orbit at *V*.

But as the whole duration of the tranſit, from firſt to laſt internal contact, will not be quite ſix hours; an obſerver, who has the Sun on his meridian at the middle of the tranſit, will be carried only from *a* to *b* during the whole time thereof. And therefore, the duration will be much leſs contracted by his own motion, than if the planet were to be twelve hours in paſſing over the Sun, as ſeen from the Earth's center.

25. The nearer Venus is to the Earth, the greater is her parallax, and the more will the true duration of her tranſit be contracted thereby; the farther ſhe is from the Earth, the contrary: ſo that the contraction will be in direct proportion to the parallax. Therefore, by obſerving, at proper places, how much the duration of the tranſit is leſs than it's true duration at the Earth's center, where it is

5 hours 58 minutes, as given by the Aſtronomical tables, the parallax of Venus will be aſcertained.

26. The above method (§ 17, *& ſeq.*) is much the ſame as was preſcribed long ago by Doctor HALLEY, but the calculations differ conſiderably from his; as will appear in the next article, which contains a tranſlation of the Doctor's whole diſſertation on that ſubject.—He had not computed his own tables when he wrote it, nor had he time before-hand to make a ſufficient number of obſervations on the motion of Venus, ſo as to determine whether the nodes of her orbit are at reſt or no; and was therefore obliged to truſt to other tables, which are now found to be erroneous.

## ARTICLE III.

*Containing Doctor* HALLEY's *Diſſertation on the method of finding the Sun's parallax and diſtance from the Earth, by the tranſit of Venus over the Sun's Diſc,* June *the 6th,* 1761. *Tranſlated from the Latin in* Motte's *Abridgment of the Philoſophical Tranſactions, Vol. I. pag.* 243; *with additional notes.*

There are many things exceedingly paradoxical, and that ſeem quite incredible to the illiterate, which yet by means of mathematical principles may be eaſily ſolved. Scarce any problem will appear more hard and difficult, than that of determining the diſtance of the Sun from the Earth very near the truth: but even this, when we are made acquainted with ſome exact obſervations, taken at places fixed upon, and choſen before-hand, will without much labour be effected. And this is what I am now deſirous to lay before this illuſtrious Society * (which I foretell will continue for ages) that I may explain before-hand to young Aſtronomers, who may perhaps live to obſerve

* The Royal Society.

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theſe things, the method whereby the immenſe diſtance of the Sun may be truly obtained, to within a five hundredth part of what it really is.

It is well known that the diſtance of the Sun from the Earth is by different Aſtronomers ſuppoſed different, according to what was judged moſt probable from the beſt conjecture that each could form. *Ptolemy* and his followers, as alſo *Copernicus* and *Tycho Brahe*, thought it to be 1200 ſemidiameters of the Earth: *Kepler* 3500 nearly; *Ricciolus* doubles the diſtance mentioned by *Kepler*, and *Hevelius* only increaſes it by one half. But the planets Venus and Mercury having, by the aſſiſtance of the teleſcope, been ſeen in the diſc of the Sun, deprived of their borrowed brightneſs, it is at length found, that the apparent diameter of the planets are much leſs than they were formerly ſuppoſed; and that the ſemidiameter of Venus ſeen from the Sun ſubtends no more than a fourth part of a minute, or fifteen ſeconds, whilſt the ſemidiameter of Mercury, at it's mean diſtance from the Sun, is ſeen under an angle only of ten ſeconds; that the ſemidiameter of Saturn ſeen from the Sun appears under the ſame angle; and that the ſemidiameter of Jupiter, the largeſt of all the planets, ſubtends an angle of no more than a third part of a minute at the Sun. Whence, keeping the proportion, ſome modern Aſtronomers have thought, that the ſemidiameter of the Earth, ſeen from the Sun, would ſubtend a mean angle between that larger one ſubtended by Jupiter, and that ſmaller one ſubtended by Saturn and Mercury; and equal to that ſubtended by Venus, (namely, fifteen ſeconds:) and have thence concluded, that the Sun is diſtant from the Earth almoſt 14000 of the Earth's ſemidiameters. But the ſame authors have on another account ſomewhat increaſed this diſtance: for, inaſmuch as the Moon's diameter is a little more than a fourth part of the diameter of the Earth, if the Sun's parallax ſhould be ſuppoſed

fifteen ſeconds, it would follow, that the body of the Moon is larger than that of Mercury; that is, that a ſecondary planet would be greater than a primary, which would ſeem inconſiſtent with the uniformity of the mundane ſyſtem. And on the contrary, the ſame regularity and uniformity ſeems ſcarcely to admit, that Venus, an inferior planet, that has no ſatellite, ſhould be greater than our Earth, which ſtands higher in the ſyſtem, and has ſuch a ſplendid attendant. Therefore, to obſerve a mean, let us ſuppoſe the ſemidiameter of the Earth ſeen from the Sun, or, which is the ſame thing, the Sun's horizontal parallax, to be twelve ſeconds and a half; according to which, the Moon will be leſs than Mercury, and the Earth larger than Venus; and the Sun's diſtance from the Earth will come out nearly 16500 of the Earth's ſemidiameters. This diſtance I aſſent to at preſent, as the true one, till it ſhall become certain what it is, by the experiment which I propoſe. Nor am I induced to alter my opinion by the authority of thoſe (however weighty it may be) who are for placing the Sun at an immenſe diſtance beyond the bounds here aſſigned, relying on obſervations made upon the vibrations of a pendulum, in order to determine thoſe exceeding ſmall angles; but which, as it ſeems, are not ſufficient to be depended upon: at leaſt, by this method of inveſtigating the parallax, it will come out ſometimes nothing, or even negative; that is, the diſtance would either become infinite, or greater than infinite; which is abſurd. And indeed, to confeſs the truth, it is hardly poſſible for a man to diſtinguiſh, with any degree of certainty, ſeconds, or even ten ſeconds, with inſtruments, let them be ever ſo ſkilfully made: therefore, it is not at all to be wondered at, that the exceſſive nicety of this matter has eluded the many and ingenious endeavours of ſuch ſkilful operators.

About forty years ago, whilſt I was in the iſland of *St. Helena*, obſerving the ſtars about the ſouth pole,

pole, I had an opportunity of obſerving, with the greateſt diligence, Mercury paſſing over the diſc of the Sun; and (which ſucceeded better than I could have hoped for) I obſerved, with the greateſt degree of accuracy, by means of a teleſcope 24 feet long, the very moment when Mercury entering upon the Sun ſeemed to touch it's limb within, and alſo the moment when going off it ſtruck the limb of the Sun's diſc, forming the angle of interior contact: whence I found the interval of time, during which Mercury then appeared within the Sun's diſc, even without an error of one ſecond of time. For the lucid line intercepted between the dark limb of the planet and the bright limb of the Sun, although exceeding fine, is ſeen by the eye; and the little dent made in the Sun's limb, by Mercury's entering the diſc, appears to vaniſh in a moment; and alſo that made by Mercury, when leaving the diſc, ſeems to begin in an inſtant.—When I perceived this, it immediately came into my mind, that the Sun's parallax might be accurately determined by ſuch kind of obſervations as theſe; provided Mercury were but nearer to the Earth, and had a greater parallax from the Sun: but the difference of theſe parallaxes is ſo little, as always to be leſs than the ſolar parallax which we ſeek; and therefore Mercury, though frequently to be ſeen on the Sun, is not to be looked upon as fit for our purpoſe.

There remains then the tranſit of Venus over the Sun's diſc; whoſe parallax, being almoſt four times as great as the ſolar parallax, will cauſe very ſenſible differences between the times in which Venus will ſeem to be paſſing over the Sun at different parts of the Earth. And from theſe differences, if they be obſerved as they ought, the Sun's parallax may be determined even to a ſmall part of a ſecond. Nor do we require any other inſtruments for this purpoſe, than common teleſcopes and clocks, only good of their kind; and in the obſervers, nothing more is needful than fidelity, diligence, and a moderate ſkill in Aſtronomy.

For there is no need that the latitude of the place ſhould be ſcrupulouſly obſerved, nor that the hours themſelves ſhould be accurately determined with reſpect to the meridian: it is ſufficient that the clocks be regulated according to the motion of the heavens, if the times be well reckoned from the total ingreſs of Venus into the Sun's diſc, to the beginning of her egreſs from it; that is, when the dark globe of Venus firſt begins to touch the bright limb of the Sun within; which moments, I know by my own experience, may be obſerved within a ſecond of time.

But on account of the very ſtrict laws by which the motions of the planets are regulated, Venus is ſeldom ſeen within the Sun's diſc: and during the courſe of more than 120 years, it could not be ſeen once; namely, from the year 1639 (when this moſt pleaſing ſight happened to that excellent youth *Horrax* our countryman, and to him only, ſince the creation) to the year 1761; in which year, according to the theories which we have hitherto found agreeable to the celeſtial motions, Venus will again paſs over the Sun on the * 26th of *May*, in the morning; ſo that at *London*, about ſix o'clock in the morning, we may expect to ſee it near the middle of the Sun's diſc, and not above four minutes of a degree ſouth of the Sun's center. But the duration of this tranſit will be almoſt eight hours; namely, from two o'clock in the morning till almoſt ten. Hence the ingreſs will not be viſible in *England*; but as the Sun will at that time be in the 16th degree of Gemini, having almoſt 23 degrees north declination, it will be ſeen without ſetting at all in almoſt all parts of the north frigid zone: and therefore the inhabitants of the coaſt of *Norway*, beyond the city of *Nidroſia*, which is called *Drontheim*, as far as the *North Cape*, will be able to obſerve Venus entering the Sun's diſc; and perhaps the ingreſs of Venus upon

* The ſixth of *June* according to the New Stile.

the

the Sun, when riſing, will be ſeen by the *Scotch*, in the northern parts of the kingdom, and by the inhabitants of the *Shetland Iſles*, formerly called *Thule*. But at the time when Venus will be neareſt the Sun's center, the Sun will be vertical to the northern ſhores of the bay of *Bengal*, or rather over the kingdom of *Pegu*; and therefore, in the adjacent regions, as the Sun, when Venus enters his diſc, will be almoſt four hours toward the eaſt, and as many to the weſt when ſhe leaves him, the apparent motion of Venus on the Sun will be accelerated by almoſt double the horizontal parallax of Venus from the Sun; becauſe Venus at that time is carried with a retrograde motion from eaſt to weſt, whilſt an eye placed upon the Earth's ſurface is whirled the contrary way, from weſt to eaſt *.

Suppoſing

* This has been already taken notice of in § 24; but I ſhall here endeavour to explain it more at large, together with ſome of the following part of the Doctor's Eſſay, by a figure.

In Fig. 1. of Plate XV. let $C$ be the center of the Earth, and $Z$ the center of the Sun. In the right line $C \upsilon Z$, make $\upsilon Z$ to $CZ$ as 726 is to 1015 (§ 12.) Let $a\,c\,b\,d$ be the Earth, $\upsilon$ Venus's place in her orbit at the time of her conjuction with the Sun; and let $T\,S\,U$ be the Sun, whoſe diameter is $31' 42''$.

The motion of Venus in her orbit is in the direction $N \upsilon n$, and the Earth's motion on it's axis is according to the order of the 24 hours placed around it in the figure. Therefore, ſuppoſing the mouth of the *Ganges* to be at $G$, when Venus is at $E$ in her orbit, and to be carried from $G$ to $g$ by the Earth's motion on it's axis, whilſt Venus moves from $E$ to $e$ in her orbit; it is plain, that the motions of Venus and the *Ganges* are contrary to each other.

The true motion of Venus in her orbit, and conſequently the ſpace ſhe ſeems to run over on the Sun's diſc in any given time, could be ſeen only from the Earth's center $C$, which is at reſt with reſpect to it's ſurface. And as ſeen from $C$, her path on the Sun would be in the right line $T\,t\,U$; and her motion therein at the rate of four minutes of a degree in an hour. $T$ is the point of the Sun's eaſtern limb which Venus ſeems to touch at the moment of her total ingreſs on the Sun, as ſeen from $C$, when Venus is at $E$ in her orbit; and $U$ is the point of the Sun's weſtern limb which ſhe ſeems to touch at the moment of her beginning of egreſs from the Sun, as ſeen from $C$, when ſhe is at $e$ in her orbit.

When

Supposing the Sun's parallax (as we have said) to be $12''\frac{1}{2}$, the parallax of Venus will be $43''$; from which subtracting the parallax of the Sun, there will remain $30''$ at least for the horizontal parallax of Venus from the Sun; and therefore the motion of Venus will be increased $45''$ at least by that parallax, whilst she passes over the Sun's disc, in those elevations of the pole which are in places near the troptic, and yet more in the neighbourhood of the equator. Now, Venus at that time will move on the Sun's disc, very nearly at the rate of four minutes of a degree in an hour; and therefore 11 minutes of time at least are to be allowed for $45''$, or three-fourths of a minute of a degree;

When the mouth of the *Ganges* is at *m* in revolving through the arc *G m g)* the Sun is on it's meridian. Therefore, since *G* and *g* are equally distant from *m* at the beginning and ending of the transit, it is plain that the Sun will be as far east of the meridian of the *Ganges* (at *G)* when the transit begins, as it will be west of the meridian of the same place (revolved from *G* to *g)* when the transit ends.

But although the beginning of the transit, or rather the moment of Venus's total ingress upon the Sun at $\mathcal{T}$, as seen from the Earth's center, must be when Venus is at *E* in her orbit, because she is then seen in the direction of the right line $C E \mathcal{T}$; yet, at the same instant of time, as seen from the *Ganges* at *G*, she will be short of her ingress on the Sun, being then seen eastward of him, in the right line *G E K*, which makes the angle $K E \mathcal{T}$ (equal to the opposite angle *G E C)* with the right line $C E \mathcal{T}$. This angle is called the angle of Venus's parallax from the Sun, which retards the beginning of the transit as seen from the banks of the *Ganges*; so that the *Ganges G* must advance a little farther toward *m*, and Venus must move on in her orbit from *E* to *R*, before she can be seen from *G* (in the right line $G R \mathcal{T}$) wholly within the Sun's disc at $\mathcal{T}$.

When Venus comes to *e* in her orbit, she will appear at *U*, as seen from the Earth's center *C*, just beginning to leave the Sun; that is, at the beginning of her egress from his western limb: but at the same instant of time, as seen from the *Ganges*, which is then at *g*, she will be quite clear of the Sun toward the west; being then seen from *g* in the right line *g e L*, which makes an angle, as *U e L* (equal to the opposite angle *C e g*) with the right line *C e U*: and this is the angle of Venus's parallax

THE EARTH'S ANNUAL ORBIT

The Orbit of Venus.

The Orbit of Mercury

EAST

WEST

Fig. 1.

The Sun's Diameter, or Minutes of a Degree

The Track or mid Path of Venus over the Sun

Evening

Midnight

Morning

Fig. 2.

The Visible Path of Venus on the Sun's Disc.

The Sun's Eastern Limb.

The Sun's Western Limb.

The difference of the Semidiameters of the Sun and Venus

J. Ferguson del.

T. Mynde sc.

a degree; and by this ſpace of time, the duration of this eclipſe cauſed by Venus will, on account of the parallax, be ſhortened. And from this ſhortening of the time only, we might ſafely enough draw a concluſion concerning the parallax which we are in ſearch of, provided the diameter of the Sun, and the latitude of Venus, were accurately known. But we cannot expect an exact computation in a matter of ſuch ſubtility.

We muſt endeavour therefore to obtain, if poſſible, another obſervation, to be taken in thoſe places where Venus will be in the middle of the Sun's diſc at midnight; that is, in places under the oppoſite meridian to the former, or about 6 hours or 90 degrees weſt of *London*; and where Venus enters upon the Sun a little before it's ſet-

parallax from the Sun as ſeen from the *Ganges* at *g*, when ſhe is but juſt beginning to leave the Sun at *U*, as ſeen from the Earth's center *C*.

Here it is plain, that the duration of the tranſit about the mouth of the *Ganges* (and alſo in the neighbouring places) will be diminiſhed by about double the quantity of Venus's parallax from the Sun at the beginning and ending of the tranſit. For Venus muſt be at *E* in her orbit when ſhe is wholly upon the Sun at *T*, as ſeen from the Earth's center *C*: but at that time ſhe is ſhort of the Sun as ſeen from the *Ganges* at *G*, by the whole quantity of her eaſtern parallax from the Sun at that time, which is the angle *KET*. [This angle, in fact, is only 23″; though it is repreſented much larger in the figure, becauſe the Earth therein is a vaſt deal too big.] Now, as Venus moves at the rate of 4′ in an hour, ſhe will move 23″ in 5 minutes 45 ſeconds: and, therefore, the tranſit will be 5 min. 45 ſeconds later of beginning at the banks of the *Ganges* than at the Earth's center.——When the tranſit is ending at *U*, as ſeen from the Earth's center *C*, Venus will be quite clear of the Sun (by the whole quantity of her weſtern parallax from him) as ſeen from the *Ganges*, which is then at *g*: and this parallax will be 22″, equal to the ſpace through which Venus moves in 5 minutes 30 ſeconds of time: ſo that the tranſit will end $5\frac{1}{2}$ minutes ſooner as ſeen from the *Ganges*, than as ſeen from the Earth's center.

Hence, the whole contraction of the duration of the tranſit at the mouth of the *Ganges* will be 11 minutes 15 ſeconds of time: for it is 5 minutes 45 ſeconds at the beginning, and 5 minutes 30 ſeconds at the end.

ting,

ting, and goes off a little after it's riſing. And this will happen under the above-mentioned meridian, and where the elevation of the north pole is about 56 degrees; that is, in a part of *Hudſon*'s *Bay*, near a place called *Port-Nelſon*. For, in this and the adjacent places, the parallax of Venus will increaſe the duration of the tranſit by at leaſt ſix minutes of time; becauſe, whilſt the Sun, from it's ſetting to it's riſing, ſeems to paſs under the pole, thoſe places on the Earth's diſc will be carried with a motion from eaſt to weſt, contrary to the motion of the *Ganges*; that is, with a motion conſpiring with the motion of Venus; and therefore, Venus will ſeem to move more ſlowly on the Sun, and to be longer in paſſing over his diſc *.

If

* In Fig. 1. of Plate XV. let $aC$ be the meridian of the eaſtern mouth of the *Ganges*; and $bC$ the meridian of *Port-Nelſon* at the mouth of *York-River* in *Hudſon*'s *Bay*, 56° north latitude. As the meridian of the *Ganges* revolves from $a$ to $c$, the meridian of *Port-Nelſon* will revolve from $b$ to $d$: therefore, whilſt the *Ganges* revolves from $G$ to $g$, through the arc $G\,m\,g$, *Port-Nelſon* revolves the contrary way (as ſeen from the Sun or Venus) from $P$ to $p$ through the arc $P\,n\,p$.——Now, as the motion of Venus is from $E$ to $e$ in her orbit, while ſhe ſeems to paſs over the Sun's diſc in the right line $T\,t\,U$, as ſeen from the Earth's center $C$, it is plain, that whilſt the motion of the *Ganges* is contrary to the motion of Venus in her orbit, and thereby ſhortens the duration of the tranſit at that place, the motion of *Port-Nelſon* is the ſame way as the motion of Venus, and will therefore increaſe the duration of the tranſit: which may in ſome degree be illuſtrated by ſuppoſing, that whilſt a ſhip is under ſail, if two birds fly along the ſide of the ſhip in contrary directions to each other, the bird which flies contrary to the motion of the ſhip will paſs by it ſooner than the bird will, which flies the ſame way that the ſhip moves.

In fine, it is plain by the figure, that the duration of the tranſit muſt be longer as ſeen from *Port-Nelſon*, than as ſeen from the Earth's center; and longer as ſeen from the Earth's center, than as ſeen from the mouth of the *Ganges*.——For *Port-Nelſon* muſt be at $P$, and Venus at $N$ in her orbit, when ſhe appears wholly within the Sun at $T$: and the ſame place muſt be at $p$, and Venus at $n$, when ſhe appears at $U$, beginning to leave the Sun.—The *Ganges* muſt be at $G$, and Venus at

If therefore it ſhould happen that this tranſit ſhould be properly obſerved by ſkilful perſons at both theſe places, it is clear, that the duration thereof will be 17 minutes longer, as ſeen from *Port-Nelſon*, than as ſeen from the *Eaſt-Indies*. Nor is it of much conſequence (if the *Engliſh* ſhall at that time give any attention to this affair) whether the obſervation be made at *Fort-George*, commonly called *Madras*, or at *Bencoolen* on the weſtern ſhore of the iſland of *Sumatra*, near the equator. But if the *French* ſhall be diſpoſed to take any pains herein, an obſerver may ſtation himſelf conveniently enough at *Pondicherry* on the weſt ſhore of the bay of *Bengal*, where the altitude of the pole is about 12 degrees. As to the *Dutch*, their celebrated mart at *Batavia* will afford them a place of obſervation fit enough for this purpoſe, provided they alſo have but a diſpoſition to aſſiſt in advancing, in this particular, the knowledge of the heavens.—And indeed I could wiſh that many obſervations of the ſame phenomenon might be taken by different perſons at ſeveral places, both that we might arrive at a greater degree of certainty by their agreement, and alſo leaſt any ſingle obſerver ſhould be deprived, by the intervention of clouds, of a ſight, which I know not whether any man living in this or the next age will ever ſee again; and on which depends the certain and adequate ſolution of a problem the moſt noble, and at any other time not to be attained to. I recommend it therefore, again and again, to thoſe curious Aſtronomers, who (when I am dead) will have an opportunity of obſerving theſe things, that they would remem-

at *R*, when ſhe is ſeen from *G* upon the Sun at *T*; and the ſame place muſt be at *g*, and Venus at *r*, when ſhe begins to leave the Sun at *U*, as ſeen from *g*. So that Venus muſt move from *N* to *n* in her orbit, whilſt ſhe is ſeen to paſs over the Sun from *Port-Nelſon*; from *E* to *e* in paſſing over the Sun, as ſeen from the Earth's center; and only from *R* to *r* whilſt ſhe paſſes over the Sun, as ſeen from the banks of the *Ganges*.

ber

ber this my admonition, and diligently apply themſelves with all their might to the making this obſervation; and I earneſtly wiſh them all imaginable ſucceſs; in the firſt place that they may not, by the unſeaſonable obſcurity of a cloudy ſky, be deprived of this moſt deſirable ſight; and then, that having aſcertained with more exactneſs the magnitudes of the planetary orbits, it may redound to their immortal fame and glory.

We have now ſhewn, that by this method the Sun's parallax may be inveſtigated to within it's five hundredth part, which doubtleſs will appear wonderful to ſome. But if an accurate obſervation be made in each of the places above marked out, we have already demonſtrated that the durations of this eclipſe made by Venus will differ from each other by 17 minutes of time; that is, upon a ſuppoſition that the Sun's parallax is $12''\frac{1}{2}$. But if the difference ſhall be found by obſervation to be greater or leſs, the Sun's parallax will be greater or leſs, nearly in the ſame proportion. And ſince 17 minutes of time are anſwerable to $12\frac{1}{2}$ ſeconds of ſolar parallax, for every ſecond of parallax there will ariſe a difference of more than 80 ſeconds of time; whence, if we have this difference true to two ſeconds, it will be certain what the Sun's parallax is, to within a 40th part of one ſecond; and therefore, his diſtance will be determined to within it's 500dth part at leaſt, if the parallax be not found leſs than what we have ſuppoſed: for 40 times $12\frac{1}{2}$ make 500.

And now I think I have explained this matter fully, and even more than I needed to have done, to thoſe who underſtand Aſtronomy: and I would have them take notice, that on this occaſion, I have had no regard to the latitude of Venus, both to avoid the inconvenience of a more intricate calculation, which would render the concluſion leſs evident; and alſo becauſe the motion of the nodes

of

of Venus is not yet diſcovered, nor can be determined but by ſuch conjunctions of the planet with the Sun as this is. For we conclude, that Venus will paſs 4 minutes below the Sun's center, only in conſequence of the ſuppoſition that the plane of Venus's orbit is immoveable in the ſphere of the fixed ſtars, and that it's nodes remain in the ſame places where they were found in the year 1639. But if Venus, in the year 1761, ſhould move over the Sun in a path more to the ſouth, it will be manifeſt that her nodes have moved backward among the fixed ſtars; and if more to the north, that they have moved forward; and that at the rate of $5\frac{1}{2}$ minutes of a degree in 100 Julian years, for every minute that Venus's path ſhall be more or leſs diſtant than the aboveſaid 4 minutes from the Sun's center. And the difference between the durations of theſe eclipſes will be ſomewhat leſs than 17 minutes of time, on account of Venus's ſouth latitude; but greater, if by the motion of the nodes forward ſhe ſhould paſs on the north of the Sun's center.

But for the ſake of thoſe, who, though they are delighted with ſydereal obſervations, may not yet have made themſelves acquainted with the doctrine of parallaxes, I choſe to explain the thing a little more fully by a ſcheme, and alſo by a calculation ſomewhat more accurate.

Let us ſuppoſe that at *London*, in the year 1761, on the 6th of *June*, at 55 minutes after V in the morning, the Sun will be in Gemini 15° 37′, and therefore that at it's center the ecliptic is inclined toward the north, in an angle of 6° 10′: and that the viſible path of Venus on the Sun's diſc at that time declines to the ſouth, making an angle with the ecliptic of 8° 28′: then the path of Venus will alſo be inclined to the ſouth, with reſpect to the equator, interſecting the parallels of declination

nation at an angle of 2° 18′ *. Let us alſo ſuppoſe, that Venus, at the forementioned time, will be at her leaſt diſtance from the Sun's center, viz. only four minutes to the ſouth; and that every hour ſhe will deſcribe a ſpace of 4 minutes on the Sun, with a retrograde motion. The Sun's ſemidiameter will be 15′ 51″ nearly, and that of Venus 37″½. And let us ſuppoſe, for trial's ſake, that the difference of the horizontal parallaxes of Venus with the Sun (which we want) is 31″, ſuch as it comes out if the Sun's parallax be ſuppoſed 12″½. Then, on the center *C* (Plate XV. Fig. 2.) let the little circle *AB*, repreſenting the Earth's diſc, be deſcribed, and let it's ſemidiameter *CB* be 31″; and let the elliptic parallels of 22 and 56 degrees of north latitude (for the *Ganges* and *Port-Nelſon*) be drawn within it, in the manner now uſed by Aſtronomers for conſtructing ſolar eclipſes. Let *BCg* be the meridian in which the Sun is, and to this, let the right line *FHG*, repreſenting the path of Venus, be inclined at an angle of 2° 18′; and let it be diſtant from the center *C* 240 ſuch parts, whereof *CB* is 31. From *C* let fall the right line *CH*, perpendicular to *FG*; and ſuppoſe Venus to be at *H* at 55 minutes after V in the morning. Let the right line *FHG* be divided into the horary ſpaces III IV, IV V, V VI, &c. each equal to *CH*; that is, to 4 minutes of a degree. Alſo, let the right line *LM* be equal to the difference of the

* This was an overſight in the Doctor, occaſioned by his placing both the Earth's axis *BCg* (Fig. 2. of Plate XV.) and the axis of Venus's orbit *CH* on the ſame ſide of the axis of the ecliptic *CK*; the former making an angle of 6° 10′ therewith, and the latter an angle of 8° 28′; the difference of which angles is only 2° 18′. But the truth is, that the Earth's axis, and the axis of Venus's orbit, will then lie on different ſides of the axis of the ecliptic, the former making an angle of 6° therewith, and the latter an angle of 8°½. Therefore, the ſum of theſe angles, which is 14°½ (and not their difference 2° 18′) is the inclination of Venus's viſible path to the equator and parallels of declination.

apparent

apparent ſemidiameters of the Sun and Venus, which is 15′ 13″½; and a circle being deſcribed with the radius *L M*, on a center taken in any point within the little circle *A B* repreſenting the Earth's diſc, will meet the right line *F G* in a point denoting the time at *London* when Venus ſhall touch the Sun's limb internally as ſeen from the place of the Earth's ſurface that anſwers to the point aſſumed in the Earth's diſc. And if a circle be deſcribed on the center *C*, with the radius *L M*, it will meet the right line *F G* in the points *F* and *G*; and the ſpaces *F H* and *G H* will be each equal to 14′ 4″, which ſpace Venus will appear to paſs over in 3 hours 40 minutes of time at *London*; therefore, *F* will fall in 11 hours 15 minutes, and *G* in IX hours 35 minutes in the morning. Whence it is manifeſt, that if the magnitude of the Earth, on account of it's immenſe diſtance, ſhould vaniſh as it were into a point; or, if being deprived of a diurnal motion, it ſhould always have the Sun vertical to the ſame point *C*; the whole duration of this eclipſe would be 7 hours 20 minutes. But the Earth in that time being whirled through 110 degrees of longitude, with a motion contrary to the motion of Venus, and conſequently the abovementioned duration being contracted, ſuppoſe 12 minutes, it will come out 7 hours 8 minutes, or 107 degrees, nearly.

Now, Venus will be at *H*, at her leaſt diſtance from the Sun's center, when in the meridian of the eaſtern mouth of the *Ganges*, where the altitude of the pole is about 22 degrees. The Sun therefore will be equally diſtant from the meridian of that place, at the moments of the ingreſs and egreſs of the planet, viz. 53½ degrees; as the points *a* and *b* (repreſenting that place in the Earth's diſc *A B*) are, in the greater parallel, from the meridian *B Cg*. But the diameter *e f* of that parallel will be to the diſtance *a b*, as the ſquare of the radius to the rectangle under the ſines of 53½ and 68 de-

grees; that is, as 1′ 2″ to 46″ 13‴. And by a good calculation (which, that I may not tire the reader, it is better to omit) I find, that a circle described on *a* as a center, with the radius *L M*, will meet the right line *F H* in the point *M*, at II hours 20 minutes 40 seconds; but that being described round *b* as a center, it will meet *H G* in the point *N* at IX hours 29 minutes 22 seconds, according to the time reckoned at *London*: and therefore, Venus will be seen entirely within the Sun at the banks of the *Ganges* for 7 hours 8 minutes 42 seconds: we have then rightly supposed, that the duration will be 7 hours 8 minutes, since the part of a minute is here of no consequence.

But adapting the calculation to *Port-Nelson*, I find, that the Sun being about to set, Venus will enter his disc; and immediately after his rising she will leave the same. That place is carried in the intermediate time through the hemisphere opposite to the Sun, from *c* to *d*, with a motion conspiring with the motion of Venus; and therefore, the stay of Venus on the Sun will be about 4 minutes longer, on account of the parallax; so that it will be at least 7 hours 24 minutes, or 111 degrees of the equator. And since the latitude of the place is 56 degrees, as the square of the radius is to the rectangle contained under the sines $55\frac{1}{2}$ and 34 degrees, so is *A B*, which is 1′ 2″, to *c d*, which is 28″ 33‴. And if the calculation be justly made, it will appear, that a circle described on *c* as a center, with the radius *L M*, will meet the right line *F H* in *O*, at II hours 12 minutes 45 seconds; and that such a circle, described on *d* as a center, will meet *H G* in *P*, at IX hours 36 minutes 37 seconds; and therefore the duration at *Port-Nelson* will be 7 hours 23 minutes 52 seconds, which is greater than at the mouth of the *Ganges*, by 15 minutes 10 seconds of time. But if Venus should pass over the Sun without having any latitude, the difference would be 18 minutes 40 seconds; and

if ſhe ſhould paſs 4′ north of the Sun's center, the difference would amount to 21 minutes 40 ſeconds, and will be ſtill greater, if the planet's north latitude be more increaſed.

From the foregoing hypotheſis it follows, that at *London*, when the Sun riſes, Venus will have entered his diſc; and that, at IX hours 37 minutes in the morning, ſhe will touch the limb of the Sun internally in going off; and laſtly, that ſhe will not entirely leave the Sun till IX hours 56 minutes.

It likewiſe follows from the ſame hypotheſis, that the center of Venus ſhould juſt touch the Sun's northern limb in the year 1769, on the third of *June*, at XI o'clock at night. So that, on account of the parallax, it will appear in the northern parts of *Norway* entirely within the Sun, which then does not ſet to thoſe parts; whilſt, on the coaſts of *Peru* and *Chili*, it will ſeem to travel over a ſmall portion of the diſc of the ſetting Sun; and over that of the riſing Sun at the *Molucca Iſlands*, and in their neighbourhood.—But if the nodes of Venus be found to have a retrograde motion (as there is ſome reaſon to believe from ſome later obſervations they have) then Venus will be ſeen every where within the Sun's diſc; and will afford a much better method for finding the Sun's parallax, by almoſt the greateſt difference in the duration of theſe eclipſes that can poſſibly happen.

But how this parallax may be deduced from obſervations made ſomewhere in the *Eaſt-Indies*, in the year 1761, both of the ingreſs and egreſs of Venus, and compared with thoſe made in it's going off with us; namely, by applying the angles of a triangle given in ſpecie to the circumference of three equal circles; ſhall be explained on ſome other occaſion.

## ARTICLE IV.

*Shewing that the whole method propoſed by the Doctor cannot be put in practice, and why.*

27. In the above Diſſertation, the Doctor has explained his method with great modeſty, and even with ſome doubtfulneſs with regard to it's full ſucceſs. For he tells us, that the Sun's parallax may only be determined within it's five hundredth part thereby, provided it be not leſs than $12''\frac{1}{2}$; that there may be a good obſervation made at *Port-Nelſon*, as well as about the banks of the *Ganges*; and that Venus does not paſs more than 4 minutes of a degree below the center of the Sun's diſc.—He has taken all proper pains not to raiſe our expectations too high, and yet, from his well-known abilities, and character as a great Aſtronomer, it ſeems mankind in general have laid greater ſtreſs upon his method, than he ever deſired them to do. Only, as he was convinced it was the beſt method by which this important problem can ever be ſolved, he recommended it warmly for that reaſon. He had not then made a ſufficient number of obſervations, whereby to determine, with certainty, whether the nodes of Venus's orbit have any motion at all; or, if they have, whether it be backward or forward with reſpect to the ſtars. And conſequently, having not then made his own tables, he was obliged to calculate from the beſt that he could find. But thoſe tables allow of no motion to Venus's nodes, and alſo reckon her conjunction with the Sun to be about half an hour too late.

28. But more modern obſervations prove, that the nodes of Venus's orbit have a motion, backward, or contrary to the order of the ſigns, with reſpect to the fixed ſtars. And this motion is allowed for, in the Doctor's tables, a great part whereof were made from his own obſervations.

And

And it appears by theſe tables, that Venus will be ſo much farther paſt her deſcending node at the time of this tranſit, than ſhe was paſt her aſcending node at her tranſit in *November* 1639, that inſtead of paſſing only 4 minutes of a degree below the Sun's center in this, ſhe will paſs almoſt 10 minutes of a degree below it: on which account, the line of her tranſit will be ſo much ſhortened, as will make her paſſage over the Sun's diſc about an hour and 20 minutes leſs than if ſhe paſſed only 4 minutes below the Sun's center, at the middle of her tranſit. And therefore, her parallax from the the Sun will be ſo much diminiſhed, both at the beginning and end of her tranſit, and at all places from which the whole of it will be ſeen, that the difference of it's durations, as ſeen from them, and as ſuppoſed to be ſeen from the Earth's center, will not amount to 11 minutes of time.

29. But this is not all: for although the tranſit will begin before the Sun ſets to *Port-Nelſon*, it will be quite over before he riſes to that place next morning, on account of it's ending ſo much ſooner than as given by the tables to which the Doctor was obliged to truſt. So that we are quite deprived of the advantage that otherwiſe would have ariſen from obſervations made at *Port-Nelſon*.

30. In order to trace this affair through all it's intricacies, and to render it as intelligible to the reader as I can, there will be an unavoidable neceſſity of dwelling much longer upon it than I could otherwiſe wiſh. And as it is impoſſible to lay down truly the parallels of latitude, and the ſituations of places at particular times, in ſuch a ſmall diſc of the Earth as muſt be projected in ſuch a ſort of diagram as the Doctor has given, ſo as to meaſure thereby the exact times of the beginning and ending of the tranſit at any given place, unleſs the Sun's diſc be made at leaſt 30 inches diameter in the projection; and to which the Doctor did not quite truſt without making ſome calculations; I

ſhall take a different method, in which the Earth's diſc may be made as large as the operator pleaſes: but if he makes it only 6 inches in diameter, he may meaſure the quantity of Venus's parallax from the Sun upon it, both in longitude and latitude, to the fourth part of a ſecond, for any given time and place; and then, by an eaſy calculation in the common rule of three, he may find the effect of the parallaxes on the duration of the tranſit. In this, I ſhall firſt ſuppoſe with the Doctor, that the Sun's horizontal parallax is $12''\frac{1}{2}$; and conſequently, that Venus's horizontal parallax from the Sun is $31''$. And after projecting the tranſit, ſo as to find the total effect of the parallax upon it's duration, I ſhall next ſhew how nearly the Sun's real parallax may be found from the obſerved intervals between the times of Venus's egreſs from the Sun, at particular places of the Earth; which is the method now taken both by the *Engliſh* and *French* Aſtronomers, and is a ſurer way whereby to come at the real quantity of the Sun's parallax, than by obſerving how much the whole contraction of duration of the tranſit is, either at *Bencoolen*, *Batavia*, or *Pondicherry*.

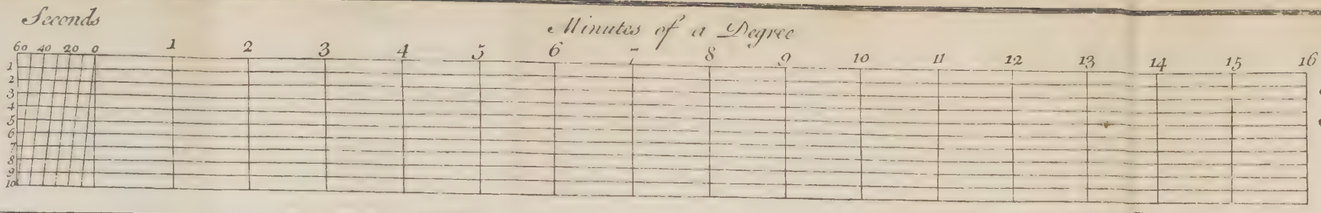
## ARTICLE V.

*Shewing how to project the tranſit of Venus on the Sun's diſc, as ſeen from different places of the Earth; ſo as to find what it's viſible duration muſt be at any given place, according to any aſſumed parallax of the Sun; and from the obſerved intervals between the times of Venus's egreſs from the Sun at particular places, to find the Sun's true horizontal parallax.*

31. The elements for this projection are as follows:

I. The true time of conjunction of the Sun and Venus; which, as ſeen from the Earth's center, and reckoned according to the equal time at *London*,

Fig. 1.




# The TRANSIT of VENUS over the SUN'S DISC, as seen from LONDON, The Eastern Mouth of the Ganges, The Island of St. Helena and Bencoolen; June the 6th 1761 By James Ferguson.

Fig. 2.

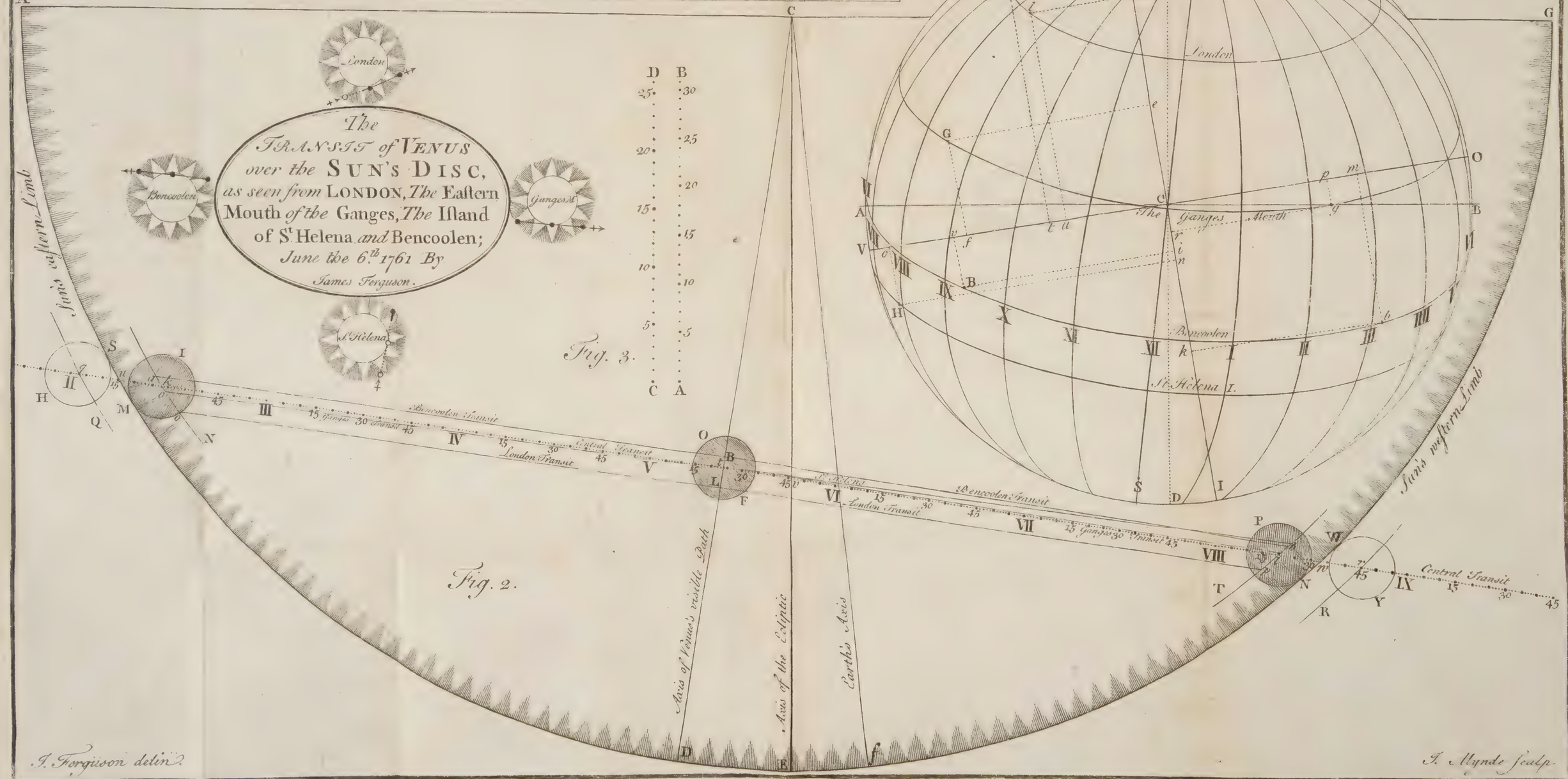
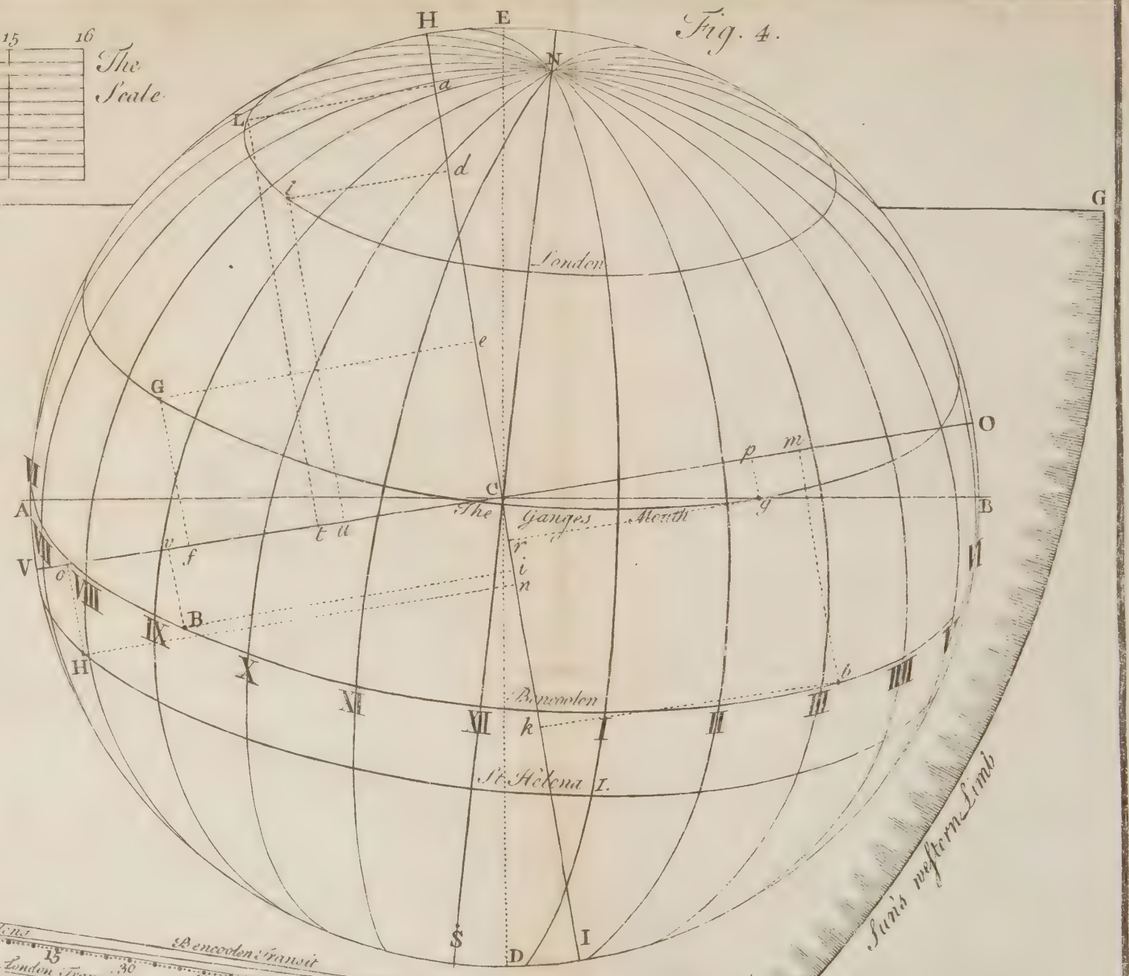



Fig. 3.




Fig. 4.




J. Ferguson delin.

J. Mynde Sculp.

*London*, is on the 6th of *June* 1761, at 46 minutes 17 seconds after V in the morning, according to Dr. HALLEY's tables.

II. The geocentric latitude of Venus at that time, $9' 43''$ south.

III. The Sun's semidiameter, $15' 50''$.

IV. The semidiameter of Venus (from the Doctor's Dissertation) $37'' \frac{1}{2}$.

V. The difference of the semidiameters of the Sun and Venus, $15' 12'' \frac{1}{2}$.

VI. Their sum, $16' 27'' \frac{1}{2}$.

VII. The visible angle which the transit-line makes with the ecliptic, $8° 31'$; the angular point (or descending node) being $1° 6' 18''$ eastward from the Sun, as seen from the Earth; the descending node being in ♎ $14° 29' 37''$, as seen from the Sun; and the Sun in ♊ $15° 35' 55''$, as seen from the Earth.

VIII. The angle which the axis of Venus's visible path makes with the axis of the ecliptic, $8° 31'$; the southern half of that axis being on the left hand (or eastward) of the axis of the ecliptic, as seen from the northern hemisphere of the Earth, which would be to the right hand, as seen from the Sun.

IX. The angle which the Earth's axis makes with the axis of the ecliptic, as seen from the Sun, $6°$; the southern half of the Earth's axis lying to the right hand of the axis of the ecliptic, in the projection; which would be to the left hand as seen from the Sun.

X. The angle which the Earth's axis makes with the axis of Venus's visible path, $14° 31'$; viz. the sum of N° VIII and IX.

XI. The true motion of Venus on the Sun, given by the tables as if it were seen from the Earth's center, 4 minutes of a degree in 60 minutes of time.

32. Theſe elements being collected, make a ſcale of any convenient length, as that of Fig. 1. in Plate XVI. and divide it into 17 equal parts, each whereof ſhall be taken for a minute of a degree; then, divide the minute next to the left hand into 60 equal parts for ſeconds, by diagonal lines, as in the figure. The reaſon for dividing the ſcale into 17 parts or minutes is, becauſe the ſum of the ſemidiameters of the Sun and Venus exceeds 16 minutes of a degree. See N° VI.

33. Draw the right line *ACG* (Fig. 2.) for a ſmall part of the ecliptic, and perpendicular thereto draw the right line *C v E* for the axis of the ecliptic on the ſouthern half of the Sun's diſc.

34. Take the Sun's ſemidiameter, 15′ 50″, from the ſcale with your compaſſes; and with that extent, as a radius, ſet one foot in *C* as a center, and deſcribe the ſemicircle *A E G* for the ſouthern half of the Sun's diſc; becauſe the tranſit is on that half of the Sun.

35. Take the geocentric latitude of Venus, 9′ 43″, from the ſcale with your compaſſes; and ſet that extent from *C* to *v*, on the axis of the ecliptic: and the point *v* ſhall be the place of Venus's center on the Sun, at the tabular moment of her conjunction with the Sun.

36. Draw the right line *C B D*, making an angle of 8° 31′ with the axis of the ecliptic, toward the left hand; and this line ſhall repreſent the axis of Venus's geocentric viſible path on the Sun.

37. Through the point of the conjunction *v*, in the axis of the ecliptic, draw the right line *q t r* for the geocentric viſible path of Venus over the Sun's diſc, at right angles to *C B D*, the axis of her orbit, which axis will divide the line of her path into two equal parts *q t* and *t r*.

38. Take Venus's horary motion on the Sun, 4′, from the ſcale with your compaſſes; and with that extent make marks along the tranſit-line *q t r*. The equal ſpaces, from mark to mark, ſhew how much

much of that line Venus moves through in each hour, as ſeen from the Earth's center, during her continuance on the Sun's diſc.

39. Divide each of theſe horary ſpaces, from mark to mark, into 60 equal parts for minutes of time; and ſet the hours to the proper marks in ſuch a manner, that the true time of conjunction of the Sun and Venus, $46\frac{1}{4}$ minutes after V in the morning, may fall into the point *v*, where the tranſit-line cuts the axis of the ecliptic. So the point *v* ſhall denote the place of Venus's center on the Sun, at the inſtant of her ecliptical conjunction with the Sun, and *t* (in the axis *C t D* of her orbit) will be the middle of her tranſit; which is at 24 minutes after V in the morning, as ſeen from the Earth's center, and reckoned by the equal time at *London*.

40. Take the difference of the ſemidiameters of the Sun and Venus, $15' 12''\frac{1}{2}$, in your compaſſes from the ſcale; and with that extent, ſetting one foot in the Sun's center *C*, deſcribe the arcs *N* and *T* with the other, croſſing the tranſit-line in the points *k* and *l*; which are the points on the Sun's diſc that are hid by the center of Venus at the moments of her two internal contacts with the Sun's limb or edge, at *M* and *N*: the former of theſe is the moment of Venus's total ingreſs on the Sun, as ſeen from the Earth's center, which is at 28 minutes after II in the morning, as reckoned at *London*; and the latter is the moment when her egreſs from the Sun begins, as ſeen from the Earth's center, which is 20 minutes after VIII in the morning at *London*. The interval between theſe two contacts is 5 hours 52 minutes.

41. The central ingreſs of Venus on the Sun is the moment when her center is on the Sun's eaſtern limb at *u*, which is at 15 minutes after II in the morning; and her central egreſs from the Sun is the moment when her center is on the Sun's weſtern limb at *w*; which is at 33 minutes after VIII in the

the morning, as ſeen from the Earth's center, and reckoned according to the time at *London*. The interval between theſe times is 6 hours 18 minutes.

42. Take the ſum of the ſemidiameters of the Sun and Venus, $16' 27''\frac{1}{2}$, in your compaſſes from the ſcale; and with that extent, ſetting one foot in the Sun's center *C*, deſcribe the arcs *Q* and *R* with the other, cutting the tranſit-line in the points *q* and *r*, which are the points in open ſpace (clear of the Sun) where the center of Venus is, at the moments of her two external contacts with the Sun's limb at *S* and *W*; or the moments of the beginning and ending of the tranſit, as ſeen from the Earth's center; the former of which is at 3 minutes after II in the morning at *London*, and the latter at 45 minutes after VIII. The interval between theſe moments is 6 hours 42 minutes.

43. Take the ſemidiameter of Venus, $37''\frac{1}{2}$, in your compaſſes from the ſcale; and with that extent as a radius, on the points *q*, *k*, *t*, *l*, *r*, as centers, deſcribe the circles *HS*, *MI*, *OF*, *PN*, *WY*, for the diſc of Venus, at her firſt contact at *S*, her total ingreſs at *M*, her place on the Sun at the middle of her tranſit, her beginning of egreſs at *N*, and her laſt contact at *W*.

44. Thoſe who have a mind to project the Earth's diſc on the Sun, round the center *C*, and to lay down the parallels of latitude and ſituations of places thereon, according to Dr. HALLEY's method, may draw *Cf* for the axis of the Earth, produced to the ſouthern edge of the Sun at *f*; and making an angle *E Cf* of 6° with the axis of the ecliptic *CE*: but he will find it very difficult and uncertain to mark the places on that diſc, unleſs he makes the Sun's ſemidiameter *AC* 15 inches at leaſt: otherwiſe the line *Cf* is of no uſe at all in this projection.—The following method is better.

45. In Fig. 3. of Plate XVI. make the line *AB* of any convenient length, and divide it into 31 equal parts, each whereof ſhall be taken for a ſecond

of

of Venus's parallax either from or upon the Sun (her horizontal parallax from the Sun being ſuppoſed to be 31′;) and taking the whole length *AB* in your compaſſes, ſet one foot in *C* (Fig. 4.) as a center, and deſcribe the circle *AEBD* for the Earth's enlightened diſc, whoſe diameter is 62″, or double the horizontal parallax of Venus from the Sun. In this diſc, draw *ACB* for a ſmall part of the ecliptic, and at right angles thereto draw *ECD* for the axis of the ecliptic. Draw alſo *NCS* both for the Earth's axis and univerſal ſolar meridian, making an angle of 6° with the axis of the ecliptic, as ſeen from the Sun; *HCI* for the axis of Venus's orbit, making an angle of 8° 31′ with *ECD*, the axis of the ecliptic; and laſtly, *VCO* for a ſmall part of Venus's orbit, at right angles to it's axis.

46. This figure repreſents the Earth's enlightened diſc, as ſeen from the Sun at the time of the tranſit. The parallels of latitude of *London*, the eaſtern mouth of the *Ganges*, *Bencoolen*, and the iſland of *St. Helena*, are laid down in it, in the ſame manner as they would appear to an obſerver on the Sun, if they were really drawn in circles on the Earth's ſurface (like thoſe on a common terreſtrial globe) and could be viſible at ſuch a diſtance.—The method of delineating theſe parallels is the ſame as already deſcribed in the XIXth Chapter, for the conſtruction of ſolar eclipſes.

47. The points where the curve-lines (called hour-circles) XI *N*, X *N*, &c. cut the parallels of latitude, or paths of the four places above-mentioned, are the points at which the places themſelves would appear in the diſc, as ſeen from the Sun, at theſe hours reſpectively. When either place comes to the ſolar meridian *NCS* by the Earth's rotation on it's axis, it is noon at that place; and the difference, in abſolute time, between the noon at that place and the noon at any other place, is in proportion to the difference of longitude of of theſe two places, reckoning one hour for every 15 de-

15 degrees of longitude, and 4 minutes for each degree: adding the time if the longitude be eaſt, but ſubtracting it if the longitude be weſt.

48. The diſtance of either of theſe places from *HCI* (the axis of Venus's * orbit) at any hour or part of an hour, being meaſured upon the ſcale *AB* in Fig. 3. will be equal to Venus's parallax in longitude, either on or from the Sun; and this parallax, being always contrary to the poſition of the place, is eaſtward as long as the place keeps on the left hand of the axis of the ecliptic, as ſeen from the Sun; and weſtward when the place gets to the right hand of the axis of the ecliptic. So that, to all the places which are poſited in the hemiſphere *HVI* of the diſc, at any given time, Venus has an eaſtern parallax of longitude; but when the Earth's diurnal motion carries the ſame places into the hemiſphere *HOI*, the parallax of Venus is weſtward.

49. When Venus has a parallax toward the eaſt, as ſeen from any given place on the Earth's ſurface, either at the time of her total ingreſs or beginning of egreſs, as ſeen from the Earth's center; add the time anſwering to this parallax to the time of ingreſs or egreſs at the Earth's center, and the ſum will be the time thereof, as ſeen from the given place on the Earth's ſurface: but when the parallax is weſtward, ſubtract the time anſwering thereto from the time of total ingreſs or beginning of egreſs as ſeen from the Earth's center, and the remainder will be the time as ſeen from the given place on the ſurface, ſo far as it is affected by this

* In the former Edition of this, I made a miſtake in taking the parallax in longitude in a line from the given place to the axis of the ecliptic, and perpendicular thereto; and the parallax in latitude from the given place to the plane of the ecliptic, and perpendicular thereto.—But in this edition, theſe errors are corrected; which make ſome ſmall differences in the quantities of the parallaxes, and in the times depending thereon; as will appear by comparing them in this with thoſe in the former edition.

paral-

parallax.—The reaſon of this is plain to every one who conſiders, that an eaſtern parallax keeps the planet back, and a weſtern parallax carries it forward, with reſpect to its true place or poſition, at any inſtant of time, as ſeen from the Earth's center.

50. The neareſt diſtance of any given place from *VCO*, the plane of Venus's orbit at any hour or part of an hour, being meaſured on the ſcale *AB* in Fig. 3, will be equal to Venus's parallax in latitude, which is northward from the true line of her path on the Sun as ſeen from the Earth's center, if the given place be on the ſouth ſide of the plane of her orbit *VCO* on the Earth's diſc; and the contrary, if the given place be on the north ſide of that plane; that is, the parallax is always contrary to the ſituation of the place on the Earth's diſc, with reſpect to the plane of Venus's orbit thereon.

51. As the line of Venus's tranſit is on the ſouthern hemiſphere of the Sun's diſc, it is plain that a northern parallax in her latitude will cauſe her to deſcribe a longer line on the Sun, than if ſhe had no ſuch parallax; and a ſouthern parallax in latitude will cauſe her to deſcribe a ſhorter line on the Sun, than if ſhe had no ſuch parallax.—And the longer this line is, the ſooner will her total ingreſs be, and the later will be her beginning of egreſs; and juſt the contrary, if the line be ſhorter.—But, to all places ſituated on the north ſide of the plane of her orbit, in the hemiſphere *VHO*, the parallax of latitude is ſouth; and to all places ſituated on the ſouth ſide of the plane of her orbit, in the hemiſphere *VIO*, the parallax of latitude is north. Therefore, the line of the tranſit will be ſhorter to all places in the hemiſphere *VHO*, than it will be as ſeen from the Earth's center, where there is no parallax at all; and longer to all places in the hemiſphere *VIO*. So that the time anſwering to this parallax muſt be added to the time of total ingreſs as ſeen from the Earth's center, and ſubtracted from

the

the beginning of egreſs as ſeen from the Earth's center, in order to have the true time of total ingreſs and beginning of egreſs as ſeen from places in the hemiſphere *VHO:* and juſt the reverſe for places in the hemiſphere *VIO.*—It was proper to mention theſe circumſtances, for the reader's more eaſily conceiving the reaſon of applying the times anſwering to the parallaxes of longitude and latitude in the ſubſequent part of this article: for it is their ſum in ſome caſes, and their difference in others, which being applied to the times of total ingreſs and beginning of egreſs as ſeen from the Earth's center, that will give the times thereof as ſeen from the given places on the Earth's ſurface.

52. The angle which the Sun's ſemidiameter ſubtends, as ſeen from the Earth, at all times of the year, has been ſo well aſcertained by late obſervations, that we can make no doubt of it's being 15′ 50″ on the day of the tranſit; and Venus's latitude has alſo been ſo well aſcertained at many different times of late, that we have very good reaſon to believe it will be 9′ 43″ ſouth of the Sun's center, at the time of her conjunction with the Sun.—If then, her ſemidiameter at that time be 37″ ½ (as mentioned by Dr. HALLEY) it appears by the projection (Fig. 2.) that her total ingreſs on the Sun as ſeen from the Earth's center, will be at 28 minutes after II in the morning (§ 40.) and her beginning of egreſs from the Sun will be 20 minutes after VIII, according to the time reckoned at *London.*

53. As the total ingreſs will not be viſible at *London*, we ſhall not here trouble the reader about Venus's parallax at that time.—But by projecting the ſituation of *London* on the Earth's diſc (Fig. 4.) for the time when the egreſs begins, we find it will then be at *l*, as ſeen from the Sun.

Draw *l d* parallel to Venus's orbit *VCO*, and *l u* perpendicular to it: the former is Venus's eaſtern parallax in longitude at her beginning of egreſs, and

and the latter is her ſouthern parallax in latitude at that time. Take theſe in your compaſſes, and meaſure them on the ſcale *AB* (Fig. 3.) and you will find the parallax in longitude to be $10''\frac{3}{4}$, and the parallax in latitude to be $21''\frac{1}{2}$.

54. As Venus's true motion on the Sun is at the rate of 4 minutes of a degree in 60 minutes of time (*See* N° XI. *of* § 31.) ſay, as 4 minutes of a degree is to 60 minutes of time, ſo is $10''\frac{3}{4}$ of a degree to 2 minutes 41 ſeconds of time; which being added to VIII hours 20 minutes (becauſe this parallax is eaſtward, § 49.) gives VIII hours 22 minutes 41 ſeconds, for the beginning of egreſs at *London*, as affected only by this parallax.—But, as Venus has a ſouthern parallax of latitude at that time, her beginning of egreſs will be ſooner; for this parallax ſhortens the line of her viſible tranſit at *London*.

55. As this parallax of latitude is $21''\frac{1}{2}$ ſouth, add it to Venus's latitude $9'\ 43''$, and the ſum will be $10'\ 4''\frac{1}{2}$; which is to be taken from the ſcale in Fig. 1. and ſet from *C* to *L* in Fig. 2. And then, if a line be drawn parallel to *t l*, it will terminate at the point *p* in the arc *T*, where Venus's center will be at the beginning of her egreſs as ſeen from *London**.—But as her center is at *l* when her egreſs begins as ſeen from the Earth's center, take *Lp* in your compaſſes, and ſetting that extent from *t* towards *l* on the central tranſit-line, you will find it to be 5 minutes ſhorter than *t l*: therefore ſubtract 5 minutes from VIII hours 22 minutes 41 ſeconds, and there will remain VIII hours 17 minutes 41 ſeconds for the viſible beginning of egreſs in the morning at *London*.

* The reaſon why the lines *o L p*, *a B b*, *c t*, and *t b*, which are the viſible tranſits at *London*, the *Ganges* mouth, *Bencoolen*, and *St. Helena*, are not parallel to the central tranſit-line *k t l*, is, becauſe the parallaxes in latitude are different at the times of ingreſs and egreſs, as ſeen from each of theſe places. The method of drawing theſe lines will be ſhewn by and by.

56. At

56. At V hours 24 minutes (which is the middle of the tranſit as ſeen from the Earth's center) *London* will be at *L* on the Earth's diſc (Fig. 4.) as ſeen from the Sun. The parallax of longitude *L a* is then $12''\frac{1}{2}$; by which, working as above directed, we find the middle of the tranſit, as ſeen from *London*, to be at V hours 20 minutes 53 ſeconds.—This is not affected by the parallax of latitude *I t*.—But *L t* meaſures 27″ on the ſcale *AB* (Fig. 3.) therefore take 27″ from the ſcale in Fig. 1. and ſet it from *t* to *L*, on the axis of Venus's path in Fig. 2. and laying a ruler to the point *L*, and the above-found point of egreſs *p*, draw *o L p* for the line of the tranſit as ſeen from *London*.

57. The eaſtern mouth of the river *Ganges* is 89 degrees eaſt from the meridian of *London*; and therefore, when the time at *London* is 28 minutes after II in the morning (§ 40.) it is 24 minutes paſt VIII in the morning (by § 47.) at the mouth of the *Ganges*; and when it is 20 minutes paſt VIII in the morning at *London* (§ 40.) it is 16 minutes paſt II in the afternoon at the *Ganges*. Therefore, by projecting that place upon the Earth's diſc, as ſeen from the Sun, it will be at *G* (in Fig. 4.) at the time of Venus's total ingreſs, as ſeen from the Earth's center, and at *g* when her egreſs begins.

Draw *G e* and *g r* parallel to the orbit of Venus *VCO*, and meaſure them on the ſcale *AB* in Fig. 3. the former will be 21″ for Venus's eaſtern parallax in longitude, at the above-mentioned time of her total ingreſs, and the latter will be $16''\frac{1}{4}$ for her weſtern parallax in longitude at the time when her egreſs begins.—The former parallax gives 5 minutes 15 ſeconds of time (by the analogy in § 54.) to be added to VIII hours 24 minutes, and the latter parallax gives 4 minutes 11 ſeconds to be ſubtracted from II hours 16 minutes; by which we have VIII hours 29 minutes 15 ſeconds, for the time of total ingreſs as ſeen from the banks of the *Ganges*, and II hours

hours 11 minutes 49 ſeconds for the beginning of egreſs, as affected by theſe parallaxes.

Draw *Gf* perpendicular to Venus's orbit *VOC*, and by meaſurement on the ſcale *AB* (Fig. 3.) it will be found to contain 10″; which being taken from the ſcale in Fig. 1. and ſet off ſouthward from the point of total ingreſs *k* (Fig. 2. as ſeen from the Earth's center) parallel to the axis of Venus's path, it will fall into the point *c* on the arc *N*.—Draw *Ct*, and taking the extent *tc* in your compaſſes, and applying it from *t* towards *k*, you will find it to fall a minute ſhort of *k*; which ſhews, that Venus's parallax in latitude ſhortens the beginning of the line of her viſible tranſit at the *Ganges* by one minute of time. Therefore, as this makes the viſible ingreſs a minute later, add one minute to the above VIII hours 29 minutes 15 ſeconds, and it will give VIII hours 30 minutes 15 ſeconds for the time of total ingreſs, in the morning, as ſeen from the eaſtern mouth of the *Ganges*. At the beginning of egreſs, the parallax of latitude *gp* is 2″ $\frac{1}{2}$ (by meaſurement of the ſcale *AB*) which will protract the beginning of egreſs by about 30 ſeconds of time, and muſt therefore be added to the above II hours 11 minutes 49 ſeconds, which will make the viſible beginning of egreſs to be at II hours 12 minutes 19 ſeconds in the afternoon.

58. *Bencoolen* is 102 degrees eaſt from the meridian of *London*; and therefore, when the time is 28 minutes paſt II in the morning at *London*, it is 16 minutes paſt IX in the morning at *Bencoolen*; and when it is 20 minutes paſt VIII in the morning at *London*, it is 8 minutes paſt III in the afternoon at *Bencoolen*. Therefore, in Fig. 4. *Bencoolen* will be at *B* at the time of Venus's total ingreſs as ſeen the Earth's center; and at *b* when her egreſs begins.

Draw *Bi* and *bk* parallel to Venus's orbit *VCO*, and meaſure them on the ſcale: the former will be found to be 22″ for Venus's eaſtern parallax in

longitude at the time of her total ingress; and the latter to be $19''\frac{1}{2}$ for her western parallax in longitude when her egress begins, as seen from the Earth's center. The first of these parallaxes gives 5 minutes 30 seconds (by the analogy in § 54.) to be added to IX hours 16 minutes, and the latter parallax gives 4 minutes 52 seconds to be subtracted from III hours 8 minutes; whence we have IX hours 21 minutes 30 seconds for the time of total ingress at *Bencoolen*; and III hours and 3 minutes 8 seconds for the time when the egress begins there, as affected by these two parallaxes.

59. Draw $B\,v$ and $b\,m$ perpendicular to Venus's orbit $V\,C\,O$, and measure them on the scale $A\,B$: the former will be $5''$ for Venus's northern parallax in latitude as seen from *Bencoolen* at the time of her total ingress; and the latter will be $15''\frac{1}{2}$ for her northern parallax in latitude when her egress begins. Take these parallaxes from the scale in Fig. 1. in your compasses, and set them off above the central transit-line, perpendicular to the axis of Venus's path; the former from the left hand of $k$ (Fig. 2.) to $a$ in the arc $N$, and the latter from the right hand of $l$ to $b$ in the arc $T$; and draw $a\,B\,b$ for the line of Venus's transit as seen from *Bencoolen*: the center of Venus being at $a$, as seen from *Bencoolen*, at the moment of her total ingress; and at $b$ at the moment when her egress begins.

But as seen from the Earth's center, the center of Venus is at $k$ in the former case, and at $l$ in the latter: so that we find the line of the transit is longer as seen from *Bencoolen* than as seen from the Earth's center, which is the effect of Venus's northern parallax in latitude.—Take $B\,a$ in your compasses, and setting that extent backward from $t$ toward $g$, on the central transit-line, you will find it will reach two minutes beyond $k$ thereon: and taking the extent $B\,b$ in your compasses, and setting it forward from $t$ towards $w$, on the central transit-line, it will be found to reach 3 minutes beyond

beyond *l* thereon. Conſequently, if we ſubtract 2 minutes from IX hours 21 minutes 30 ſeconds (above found) we have IX hours 19 minutes 30 ſeconds, in the morning, for the time of total ingreſs as ſeen from *Bencoolen:* and if we add 3 minutes to the above found III hours 3 minutes 8 ſeconds, we ſhall have III hours 6 minutes 8 ſeconds after noon, for the time when the egreſs begins as ſeen from *Bencoolen.*

60. The whole duration of the tranſit, from total ingreſs to beginning of egreſs, as ſeen from the Earth's center, is 5 hours 52 minutes (by § 40.) but the whole duration from total ingreſs to beginning of egreſs, as ſeen from *Bencoolen*, is only 5 hours 46 minutes 38 ſeconds; which is 5 minutes 22 ſeconds leſs than as ſeen from the Earth's center: and this 5 minutes 22 ſeconds is the whole effect of the parallaxes (both in longitude and latitude) on the duration of the tranſit at *Bencoolen.*

But the duration as ſeen at the mouth of the *Ganges*, from ingreſs to egreſs, is ſtill leſs; for it is only 5 hours 42 minutes 4 ſeconds: which is 9 minutes 56 ſeconds leſs than as ſeen from the Earth's center, and 4 minutes 34 ſeconds leſs than as ſeen at *Bencoolen.*

61. The iſland of *St. Helena* (to which only a ſmall part of the tranſit is viſible at the end) will be at *H* (as in Fig. 4.) when the egreſs begins as ſeen from the Earth's center. And ſince the middle of that iſland is 6° weſt from the meridian of *London*, and the ſaid egreſs begins when the time at *London* is 20 minutes paſt VIII in the morning, it will then be only 56 minutes paſt VII in the morning at *St. Helena.*

Draw *Hn* parallel to Venus's orbit *VCO*, and *Ho* perpendicular to it; and by meaſuring them on the ſcale *AB* (Fig. 3.) the former will be found to amount to 29″ for Venus's eaſtern parallax in longitude, as ſeen from *St. Helena*, when her egreſs be-

gins as ſeen from the Earth's center; and the latter to be 6″ for her northern parallax in latitude at that time.

By the analogy in § 54, this parallax of longitude gives 10 minutes 2 ſeconds of time; which being added (on account of it's being eaſtward) to VII hours 56 minutes, gives VIII hours 6 minutes 2 ſeconds for the beginning of egreſs at *St. Helena*, as affected by this parallax.—But 6″ of parallax in latitude (applied as in the caſe of *Bencoolen*) lengthens out the end of the tranſit-line by 1 minute; which being added to VIII hours 6 minutes 2 ſeconds, gives VIII hours 7 minutes 2 ſeconds for the beginning of egreſs, as ſeen from *St. Helena*.

62. We ſhall now collect the above-mentioned times into a ſmall table, that they may be ſeen at once, as follows. *M* ſignifies morning, *A* afternoon.

| | | Total ingreſs. H. M. S. | Beg. of egreſs. H. M. S. | Duration. H. M. S. |
|---|---|---|---|---|
| At | The Earth's center | II 28 0 *M.* | VIII 20 0 *M.* | 5 52 0* |
| | *London* | Inviſible. *M.* | VIII 17 41 *M.* | — — — |
| | The *Ganges* mouth | VIII 30 15 *M.* | II 12 19 *A.* | 5 42 4 |
| | *Bencoolen* | IX 19 30 *M.* | III 6 8 *A.* | 5 46 38 |
| | *St. Helena* | Inviſible *M.* | VIII 7 2 *M.* | — — — |

63. The times at the three laſt-mentioned places are reduced to the meridian of *London*, by ſubtracting 5 hours 56 minutes from the times of ingreſs and egreſs at the *Ganges*; 6 hours 48 minutes from the times thereof at *Bencoolen*; and adding 24 minutes to the time of beginning of egreſs at

* This duration, as ſeen from the Earth's center, is on ſuppoſition that the ſemidiameter of Venus will be found equal to 37″ ½, on the Sun's diſc, as ſtated by Dr. *Halley* (ſee Art. V. § 31.) to which all the other durations are accommodated — But, from later obſervations, it his highly probable, that the ſemidiameter of Venus will be found not to exceed 30″ on the Sun; and if ſo, the duration between the two internal contacts, as ſeen from the Earth's center, will be 5 hours 58 minutes; and the durations, as ſeen from the above-mentioned places, will be lengthened very nearly in the ſame proportion.

*St.*

*St. Helena:* and being thus reduced, they are as follows.

| | | Total ingreſs. H. M. S. | Beg. of egreſs, H. M. S. | |
|---|---|---|---|---|
| Times at *London* for | *Ganges* mouth | II 34 15 *M.* | VIII 16 19 *M.* | Durations as above. |
| | *Bencoolen* | II 31 30 *M.* | VIII 18 8 *M.* | |
| | *St. Helena* | Inviſible. *M.* | VIII 31 2 *M.* | |

64. All this is on ſuppoſition, that we have the true longitudes of the three laſt-mentioned places, that the Sun's horizontal parallax is $12''\frac{1}{2}$, that the true latitude of Venus is given, and that her ſemidiameter will ſubtend an angle of $37''\frac{1}{2}$ on the Sun's diſc.

As for the longitudes, we muſt ſuppoſe them true, until the obſervers aſcertain them, which is a very important part of their buſineſs; and without which they can by no means find the interval of abſolute time that elapſeth between either the ingreſs or egreſs, as ſeen from any two given places: and there is much greater dependance to be had on this elapſe, than upon the whole contraction of duration at any given place, as it will undoubtedly afford a ſurer baſis for determining the Sun's parallax.

65. I have good reaſon to believe, that the latitude of Venus, as given in § 31, will be found by obſervation to be very near the truth; but that the time of conjunction there mentioned will be found to anticipate the true time by almoſt 5 minutes; that Venus's ſemidiameter will ſubtend an angle of no more than 30″ on the Sun's diſc; and that the middle of her tranſit, as ſeen from the Earth's center, will be at 29 minutes after V in the morning, as reckoned by the equal time at *London*.

66. Subtract VIII hours 17 minutes 41 ſeconds, the time when the egreſs begins at *London*, from VIII hours 31 minutes 2 ſeconds, the time reckoned at *London* when the egreſs begins at *St. Helena*, and there will remain 13 minutes 21 ſeconds (or 801

ſeconds) for their difference, or elapſe, in abſolute time, between the beginning of egreſs as ſeen from theſe two places.

Divide this elapſe of 801 ſeconds by the Sun's parallax $12''\frac{1}{2}$; and the quotient will be 64 ſeconds and a ſmall fraction. So that for each ſecond of a degree in the Sun's horizontal parallax (ſuppoſing it to be $12\frac{1}{2}$) there will be a difference or elapſe of 64 ſeconds of abſolute time between the beginning of egreſs as ſeen from *London*, and as ſeen from *St. Helena*: and conſequently 32 ſeconds of time for every half ſecond of the Sun's parallax; 16 ſeconds of time for every fourth part of a ſecond of the Sun's parallax; 8 ſeconds of time for the eighth part of a ſecond of the Sun's parallax; and full 4 ſeconds for a ſixteenth part of the Sun's parallax.

For, in ſuch a ſmall angle as that of the Sun's parallax, the arc is equal both to it's ſine and to it's tangent: and therefore, the quantity of this parallax is in direct proportion to the abſolute difference in the time of egreſs ariſing from it, at different parts of the Earth.

67. Therefore, when this difference is aſcertained by good obſervations, made at different places, and compared together, the true quantity of the Sun's parallax will be very nearly determined. For, ſince it may be preſumed that the beginning of egreſs can be obſerved within 2 ſeconds of it's real time, the Sun's parallax may be then found within the 32d part of a ſecond of it's true quantity; and conſequently, his diſtance may be found within a 400th part of the whole, provided his parallax be not leſs that $12''\frac{1}{2}$; for 32 times $12\frac{1}{2}$ is 400.

68. But ſince Dr. HALLEY has aſſured us, that he had obſerved the two internal contacts of the planet Mercury with the Sun's edge ſo exactly, as not to err one ſecond in the time thereof, we may well imagine that the internal contacts of Venus with the Sun may be obſerved with as great

great accuracy. So that we may hope to have the abſolute interval between the moments of her beginning of egreſs, as ſeen from *London* and from *St. Helena*, true to a ſecond of time; and if ſo, the Sun's parallax may be determined to the 64th part of a ſecond, provided it be not leſs than $12''\frac{1}{2}$; and conſequently his diſtance may be found, within it's 800th part, for 64 times $12\frac{1}{2}$ is 800: which is ſtill nearer the truth than Dr. HALLEY expected it might be found, by obſerving the whole duration of the tranſit in the *Eaſt-Indies* and at *Port-Nelſon*. So that our preſent Aſtronomers have judiciouſly reſolved to improve the Doctor's method, by taking only the interval between the abſolute times of it's ending at different places. If the Sun's parallax be greater or leſs than $12''\frac{1}{2}$, the elapſe or difference of abſolute time between the beginning of egreſs at *London* and *St. Helena* will be found by obſervation to be greater or leſs than 801 ſeconds accordingly.

69. There will alſo be a great difference between the abſolute times of egreſs at *St. Helena* and the northern parts of *Ruſſia*, which would make theſe places very proper for obſervation. The difference between them at *Tobolſk* in *Siberia* and at *St. Helena* will be 11 minutes, according to DE L'ISLE's map: at *Archangel* it will be but about 40 ſeconds leſs than at *Tobolſk*; and only a minute and a quarter leſs at *Peterſburgh*, even if the Sun's parallax be no more than $10''\frac{1}{2}$. At *Wardhus* the ſame advantage would nearly be gained as at *Tobolſk*: but if the obſervers could go ſtill farther to the eaſt, as to *Yakoutſk* in *Siberia*, the advantage would be ſtill greater; for, as Mr. DE L'ISLE very juſtly obſerves, in a memoir preſented to the *French* king with his map of the tranſit, the difference of time between Venus's egreſs from the Sun at *Yakoutſk* and at the *Cape of Good Hope* will be $13\frac{1}{2}$ minutes.

70. This method requires that the longitude of each place of obſervation be aſcertained to the

greateſt degree of nicety, and that each obſerver's clock be exactly regulated to the equal time at his place: for without theſe particulars it would be impoſſible for the obſervers to reduce the times to thoſe which are reckoned under any given meridian; and without reducing the obſerved times of egreſs at different places to the time at ſome given place, the abſolute time that elapſeth between the egreſs at one place and at another could not be found. But the longitudes may be found, by obſerving the eclipſes of Jupiter's ſatellites; and a true meridian, for regulating the clock, to the time at any place, may be had, by obſerving when any given ſtar, within 20 or 30 degrees of the pole, is ſtationary, with regard to it's azimuth, on the eaſt and weſt ſides of the pole: the pole itſelf being the middle point between theſe two ſtationary poſitions of the ſtar. And it is not material for the obſervers to know exactly either the true angular meaſure of the Sun's diameter, or of Venus's, in this caſe; for whatever their diameters be, it will make no ſenſible difference in the obſerved interval between the ſame contact, as ſeen from different places.

71. In the geometrical conſtruction of tranſits, the ſcale *AB* (Fig. 3. of Plate XVI.) may be divided into any given number of equal parts, anſwering to any aſſumed quantity of Venus's horizontal parallax from the Sun (which is always the difference between the horizontal parallax of Venus and that of the Sun) provided the whole length of the ſcale be equal to the ſemidiameter of the Earth's diſc in Fig. 4.—Thus, if we ſuppoſe Venus's horizontal parallax from the Sun to be only 26″ (inſtead of 31″) in which caſe the Sun's horizontal parallax muſt be 10″.3493, as in § 20, the reſt of the projection will anſwer to that ſcale: as *CD*, which contains only 26 equal parts, is the ſame length as *AB*, which contains 31. And by working in all other reſpects as taught from § 45 to

§ 62,

§ 62, you will find the times of total ingreſs and beginning of egreſs; and conſequently, the duration of the tranſit at any given place, which muſt reſult from ſuch a parallax.

72. In projections of this kind, it may be eaſily conceived, that a right line paſſing continually through the center of Venus, and a given point of the Earth, and produced to the Sun's diſc, will mark the path of Venus on the Sun as ſeen from the given point of the Earth: and in this there are three caſes. 1. When the given point is the Earth's center, at which there is no parallax, either in longitude or latitude. 2. When the given point is one of the poles, where there is no parallax of longitude; but a parallax of latitude, whoſe quantity is eaſily determined, by letting fall a perpendicular from the pole upon the plane of Venus's orbit, and ſetting off the parallax of latitude on this perpendicular: and here, the polar tranſit-lines will be parallel to the central; as the poles have no motion ariſing from the Earth's diurnal rotation. 3. The laſt caſe is, when the given point of the Earth is any point of it's ſurface, whoſe latitude is leſs than 90 degrees: then there is a parallax in latitude proportional to the perpendicular let fall upon the aboveſaid plane, from the given point; and a parallax in longitude proportional to the perpendicular let fall upon the axis of that plane, from the ſaid given point. And the effect of this laſt will be to alter the tranſit-line, both in poſition and length; and will prevent it's being parallel to the central tranſit-line, unleſs when it's axis and the axis of the Earth coincide, as ſeen from the Sun; which is a thing that may not happen in many ages.

ARTICLE

## ARTICLE VI.

*Concerning the map of the tranſit.* Plate XVII.

73. The title of this map, and the lines drawn upon it, together with the words annexed to theſe lines, and the numbers [hours and minutes] on the dotted lines, explain the whole of it ſo well, that no farther deſcription ſeems requiſite.

74. So far as I can examine the map by a good globe, the black curve lines are in general pretty well laid down, for ſhewing at what places the tranſit will begin, or end, at ſun-riſing or ſun-ſetting, to all thoſe places through which they are drawn, according to the times mentioned in the map. Only I queſtion much whether the tranſit will begin at ſun-riſe to any place in *Africa*, that is weſt of the *Red-Sea*; and am pretty certain that the Sun will not be riſen to the northmoſt part of *Madagaſcar* when the tranſit begins, as M. De L'Isle reckons the firſt contact of Venus with the Sun to be the beginning of the tranſit. So that the line which ſhews the entrance of Venus in the Sun's diſc at ſun-riſing, ſeems to be a little too far weſt in the map, at all places which are ſouth of *Aſia Minor*: but in *Europe*, I think it is very well.

75. In delineating this map, I had M. De L'Isle's map of the tranſit before me. And the only difference between his map and this is, 1. That in his map, the times are computed to the meridian of *Paris*; in this they are reduced to the meridian of *London*. 2. I have changed his meridional projection into that of the equatorial; by which, I apprehend, that the black curve lines, ſhewing at what places the tranſit begins, or ends, with the riſing or ſetting Sun, appear more natural to the eye, and are more fully ſeen at once, than in the map from which I copied: for, in that map, the lines are interrupted and broke in the meridian

# A MAP of the EARTH, Upon which are marked the Hours and Minutes of true Times of the Entrance and Exit of VENUS, in its Passage over the SUN's DISC, June 6th 1761. The Times are computed to the Meridian of LONDON, and that which is expressed upon each dotted Line shews when the Transit begins or ends at all those Places which the same Line passes through. The beginning is between II and III in the Morning and the end between VIII and IX. The four black curve Lines shew at what Places the Transit begins, and at what Places its ends, both at Sun-rising and Sun-setting.

PACIFIC OCEAN

To this Space the beginning and part of the Transit is Visible

The Transit begins at Sun rise

The Transit ends at Sun set

The Equator

NORTH AMERICA

FROZEN SEA

Nor. Pole

ASIA

EUROPE

AFRICA

INDIAN OCEAN

Arabia

ATLANTIC OCEAN

Terra Firma

Hispaniola

Cuba

Jamaica

Barbadoes

Cayenne

Azores I.

Cape Verd Islands

Britain

Ireland

Newfound land

Japan

Yedo

Manila

Borneo

Java

New Holland

New Britain

Solomon Isles

Celebes

Batavia

Siam

Pekin

Macao

Yakoutski

Archangel

Petersburg

Agra

Golconda

Surat

Goa

Ceylon

Mecca

Jerusalem

Constantinople

Madrid

Paris

Berlin

Lisbon

Tripoly

Fez

Morocco

Dongola

Mina

Benin

Senegal

Cape Verd

C. Blanco

Mexico

Acapulco

Quebec

Boston

Carthagena

Panama

Barbadoes

To this Space part of the Transit and its end is Visible

The Transit begins at Sun rise

The Transit ends at Sun set

To this Space the beginning & part of the Transit is Visible

SOUTH SEA

To this Space the whole Transit is Visible

To this Space the whole Transit is Visible

To this Space part of the Transit and its end is Visible

To this Space the beginning & part of the Transit is Visible

The Transit begins at Sun set

The Transit ends at Sun rise

The Transit begins at Sun rise

18 Days within this Circle on the 6th of June

South Pole

Cape Horn

Lima

Quilca

Buenos Aires

La Plata R.

SOUTH AMERICA

Mascaren

C. of Good Hope

Madagascar

Trinidado

S. Salvador

Amazons River

St Helena

Solinda

ETHIOPIC OCEAN

AFRICA

East Longitude from LONDON

West Longitude from LONDON

A. Ferguson delin.

T. Mynde sculp.

that divides the hemiſpheres; and the places where they ſhould join cannot be perceived ſo readily by thoſe who are not well ſkilled in the nature of ſtereographical projections.—The like may be ſaid of many of the dotted curve lines, on which are expreſſed the hours and minutes of the beginning or ending of the tranſit, which are the abſolute times at theſe places through which the lines are drawn, computed to the meridian of *London*.

## ARTICLE VII.

*Containing an Account of Mr.* HORROX's *Obſervation of the Tranſit of Venus over the Sun, in the Year* 1639; *as it is publiſhed in the* Annual Regiſter *for the Year* 1761.

76. When *Kepler* firſt conſtructed his (the Rudolphine) Tables upon the obſervations of *Tycho*, he ſoon became ſenſible that the Planets Mercury and Venus would ſometimes paſs over the Sun's diſc; and he predicted two tranſits of Venus, one for the year 1631, and the other for 1761, in a tract publiſhed at *Leipſick* in 1629, entitled, *Admonitio ad Aſtronomos, &c.* *Kepler* died ſome days before the tranſit in 1631, which he had predicted was to have happened. *Gaſſendi* looked for it at *Paris*, but in vain (ſee *Mercurius in Sole viſus, & Venus inviſa.*) In effect, the imperfect ſtate of the Rudolphine Tables was the cauſe that the tranſit was expected in 1631, when none could be obſerved; and thoſe very tables did not give reaſon to expect one in 1639, when one was really obſerved.

When our illuſtrious countryman Mr. HORROX firſt applied himſelf to Aſtronomy, he computed Ephemerides for ſeveral years, from *Lanſbergius*'s Tables. After continuing his labours for ſome time, he was enabled to diſcover the imperfection of theſe tables; upon which he laid aſide his work, intending

intending to determine the poſitions of the ſtars from his own obſervations. But that the former part of his time ſpent in calculating from *Lanſbergius* might not be thrown away, he made uſe of his Ephemerides to point out to him the ſituations of the planets. From hence he foreſaw when their conjunctions, their appulſes to be fixed ſtars, and the moſt remarkable phenomena in the heavens would happen; and prepared himſelf with the greateſt care to obſerve them.

Hence he was encouraged to wait for the important obſervation of the tranſit of Venus in the year 1639; and no longer thought the former part of his time miſpent, ſince his attention to *Lanſbergius*'s Tables had enabled him to diſcover that the tranſit would certainly happen on the 24th of *November*. However, as theſe tables had ſo often deceived him, he was unwilling to rely on them entirely, but conſulted other tables, and particularly thoſe of *Kepler*; accordingly, in a letter to his friend *William Crabtree* of *Manchester*, dated *Hool*, *October* 26, 1639, he communicated his diſcovery to him, and earneſtly deſired him to make whatever obſervation he poſſibly could with his teleſcope, particularly to meaſure the diameter of the planet Venus; which, according to *Kepler*, would amount to 7 minutes of a degree, and according to *Lanſbergius* to 11 minutes; but which, according to his own proportion, he expected it would hardly exceed one minute. He adds, that according to *Kepler*, the conjunction will be *November* 24, 1639, at 8 hours 1 minute A. M. at *Manchester*, and that the planet's latitude would be 14′ 10″ ſouth; but according to his own corrections, he expected it to happen at 3 hours 57 min. P. M. at *Manchester*, with 10′ ſouth latitude. But becauſe a ſmall alteration in *Kepler*'s numbers would greatly alter the time of conjunction, and the quantity of the planet's latitude, he adviſes to watch the whole day, and even on the preceding afternoon, and the morning

of

of the 25th, though he was entirely of opinion that the tranſit would happen on the 24th.

After having fully weighed and examined the ſeveral methods of obſerving this uncommon phenomenon, he determined to tranſmit the Sun's image through a teleſcope into a dark chamber, rather than through a naked aperture, a method greatly commended by *Kepler*; for the Sun's image is not given ſufficiently large and diſtinct by the latter, unleſs at a very great diſtance from the aperture, which the narrowneſs of his ſituation would not allow of; nor would Venus's diameter be well defined, unleſs the aperture were very ſmall; whereas his teleſcope, which rendered the ſolar ſpots diſtinctly viſible, would ſhew him Venus's diameter well defined, and enable him to divide the Sun's limb more accurately.

He deſcribed a circle on paper which nearly equalled ſix inches, the narrowneſs of the place not allowing a larger ſize; but even this ſize admitted diviſions ſufficiently accurate. He divided the circumference into 360 degrees, and the diameter into 30 equal parts, each of which were ſubdivided into 4, and the whole therefore into 120. The ſubdiviſion might have ſtill been carried farther, but he truſted rather to the accuracy and niceneſs of his eye.

When the time of obſervation drew near, he adjuſted the apparatus, and cauſed the Sun's diſtinct image exactly to fill the circle on the paper; and though he could not expect the planet to enter upon the Sun's diſc before three o'clock in the afternoon of the 24th, from his own corrected numbers, upon which he chiefly relied; yet, becauſe the calculations in general from other tables gave the time of conjunction much ſooner, and ſome even on the 23d, he obſerved the Sun from the time of it's riſing to nine o'clock; and again, a little before ten; at noon, and at one in the afternoon: being called in the intervals to buſineſs of the

the higheſt moment, which he could not neglect. But in all theſe times he ſaw nothing on the Sun's face, except one ſmall ſpot, which he had ſeen on the preceding day; and which alſo he afterward ſaw on ſome of the following days.

But at 3 hours 15 minutes in the afternoon, which was the firſt opportunity he had of repeating his obſervations, the clouds were entirely diſperſed, and invited him to ſeize this favourable occaſion, which ſeemed to be providentially thrown in his way; for he then beheld the moſt agreeable ſight, a ſpot, which had been the object of his moſt ſanguine wiſhes, of an unuſual ſize, and of a perfectly circular ſhape, juſt wholly entered upon the Sun's diſc on the left ſide; ſo that the limbs of the Sun and Venus perfectly coincided in the very point of contact. He was immediately ſenſible that this ſpot was the planet Venus, and applied himſelf with the utmoſt care to proſecute his obſervations.

And, *Firſt*, with regard to the inclination, he found, by means of a diameter of the circle ſet perpendicular to the horizon, the plane of the circle being ſomewhat reclined on account of the Sun's altitude, that Venus had wholly entered upon the Sun's diſc, at 3 hours 15 minutes, at about 62° 30′ (certainly between 60° and 65°) from the vertex toward the right hand. (Theſe were the appearances within the dark chamber, where the Sun's image and motion of the planet thereon were both inverted and reverſed.) And this inclination continued conſtant, at leaſt to all ſenſe, till he had finiſhed the whole of his obſervation.

*Secondly*, The diſtances obſerved afterward between the centers of the Sun and Venus were as follows. At 3 hours 15 minutes by the clock, the diſtance was 14′ 24″; at 3 hours 35 minutes, the diſtance was 13′ 30″; at 3 hours 45 minutes, the diſtance was 13′ 0″. The apparent time of ſunſetting was at 3 hours 50 minutes—the true time

3 hours

3 hours 45 minutes—refraction keeping the Sun above the horizon for the ſpace of 5 minutes.

*Thirdly*, He found Venus's diameter, by repeated obſervations, to exceed a thirtieth part of the Sun's diameter, by a ſixth, or at moſt a fifth ſubdiviſion. —The diameter therefore of the Sun to that of Venus may be expreſſed, as 30 to 1.12. It certainly did not amount to 1.30, nor yet to 1.20. And this was found, by obſerving Venus as well when near the Sun's limb, as when farther removed from it.

The place where this obſervation was made, was an obſcure village called *Hool*, about 15 miles miles northward of *Liverpool*. The latitude of *Liverpool* had been often determined by *Horrox* to be 53° 20′; and therefore, that of *Hool* will be 53° 35′. The longitude of both ſeemed to him to be about 22° 30′ from the *Fortunate Iſlands*; that is 14° 15′ to the weſt of *Uraniburg*.

Theſe were all the obſervations which the ſhortneſs of the time allowed him to make upon this moſt remarkable and uncommon ſight; all that could be done however in ſo ſmall a ſpace of time, he very happily executed; and ſcarce any thing farther remained for him to deſire. In regard to the inclination alone, he could not obtain the utmoſt exactneſs; for it was extremely difficult, from the Sun's rapid motion, to obſerve it to any certainty within the degree. And he ingeniouſly confeſſes that he neither did, nor could poſſibly perform it. The reſt are very much to be depended upon; and as exact as he could wiſh.

Mr. *Crabtree*, at *Mancheſter*, whom Mr. *Horrox* had deſired to obſerve this tranſit, and who in mathematical knowledge was inferior to few, very readily complied with his friend's requeſt; but the ſky was very unfavourable to him, and he had only one ſight of Venus on the Sun's diſc, which was about 3 hours 35 minutes by the clock; the Sun then, for the firſt time, breaking out from the clouds;

clouds; at which time, he sketched out Venus's situation upon paper, which *Horrox* found to coincide with his own observations.

Mr. *Horrox*, in his treatise on this subject, published by *Hevelius*, and from which almost the whole of this account has been collected, hopes for pardon from the astronomical world, for not making his intelligence more publick; but his discovery was made too late. He is desirous however, in the spirit of a true philosopher, that other astronomers were happy enough to observe it, who might either confirm or correct his observations. But such confidence was reposed in the tables at that time, that it does not appear that this transit of Venus was observed by any besides our two ingenious countrymen, who prosecuted their astronomical studies with such eagerness and precision, that they must very soon have brought their favourite science to a degree of perfection unknown at those times. But unfortunately Mr. *Horrox* died on the 3d of *January* 1640-1, about the age of 25, just after he had put the last hand to his treatise, entitled, *Venus in Sole visa*, in which he shews himself to have had a more accurate knowledge of the dimensions of the Solar System than his learned commentator *Hevelius*.——*So far the Annual Register.*

In the year 1691 *, Dr. HALLEY gave in a paper upon the transit of Venus (See *Lowthorpe*'s Abridgement of the Philosophical Transactions, pag. 434.) in which he observes, from the tables then in use, that Venus returns to a conjunction with the Sun in her ascending node in a period of 18 years, wanting 2 days 10 hours $52\frac{1}{2}$ minutes; but that in the second conjunction she will have got 24′ 41″ farther to the south than in the preceding. That after a period of 235 years 2 hours 10 minutes 9 seconds, she returns to a conjunction more to the north by 11′ 33″; and after 243 years, wanting 43

* See the *Connoissance des Temps* for *A. D.* 1761.

 minutes,

minutes, in a point more to the ſouth by 13′ 8″. But if the ſecond conjunction is in the year next after leap year, it will be a day later.

The intervals of the conjunctions at the deſcending node are ſomewhat different. The ſecond happens in a period of 8 years, wanting 2 days 6 hours 55 minutes, Venus being got more to the north by 19′ 58″. After 235 years 2 days 8 hours 18 minutes, ſhe is 9′ 21″ more ſoutherly: only, if the firſt year is a biſſextile, a day muſt be added. And after 243 years 0 days 1 hour 23 minutes, the conjunction happens 10′ 37″ more to the north; and a day later, if the firſt year was biſſextile. It is ſuppoſed, as in the old ſtile, that all the centurial years are biſſextiles.

Hence, Dr. HALLEY finds the years in which a tranſit may happen at the aſcending node, in the month of *November* (old ſtile) to be theſe—918, 1161, 1396, 1631, 1639, 1874, 2109, 2117: and the tranſits in the month of *May* (old ſtile) at the deſcending node, to be in theſe years—1048, 1283, 1518, 1526, 1761, 1769, 1996, 2004.

In the firſt caſe, Dr. HALLEY makes the viſible inclination of Venus's orbit to be 9° 5′, and her horary motion on the Sun 4′ 7″. In the latter, he finds her viſible inclination to be 8′ 28″, and her horary motion 4′ 0″. In either caſe, the greateſt poſſible duration of a tranſit is 7 hours 56 minutes.

Dr. HALLEY could even then conclude, that if the interval in time between the two interior contacts of Venus with the Sun could be meaſured to the exactneſs of a ſecond, in two places properly ſituated, the Sun's parallax might be determined within it's 500dth part.—But ſeveral years after, he explained this concluſion more fully, in a paper concerning the tranſit of Venus in the year 1761; which was publiſhed in the Philoſophical Tranſactions, and of which the third of the preceding articles is a tranſlation; the original having been wrote in *Latin* by the Doctor.

## ARTICLE VIII.

*Containing a ſhort account of ſome obſervations of the Tranſit of Venus*, A. D. 1761, June 6*th*, *New Stile*; *and the diſtances of the planets from the Sun, as deduced from thoſe obſervations.*

Early in the morning, when every aſtronomer was prepared for obſerving the tranſit, it unluckily happened, that both at *London*, and the Royal Obſervatory at *Greenwich*, the ſky was ſo overcaſt with clouds, as to render it doubtful whether any part of the tranſit ſhould be ſeen:—and it was 38 minutes 21 ſeconds paſt 7 o'clock (apparent time) at *Greenwich*, when the Rev. Dr. *Bliſs*, our Aſtromer Royal, firſt ſaw Venus on the Sun; at which inſtant, the center of Venus preceded the Sun's center by 6′ 18″.9 of right aſcenſion, and was ſouth of the Sun's center by 18′ 42″.1 of declination.—From that time to the beginning of egreſs the Doctor made ſeveral obſervations, both of the difference of right aſcenſion and declination of the centers of the Sun and Venus; and at laſt found the beginning of egreſs, or inſtant of the internal contact of Venus with the Sun's limb, to be at 8 hours 19 minutes 0 ſeconds apparent time.—From the Doctor's own obſervations, and thoſe which were made at *Shirburn* by another gentleman, he has computed, that the mean time at *Greenwich* of the ecliptical conjunction of the Sun and Venus was at 51 minutes 20 ſeconds after 5 o'clock in the morning; that the place of the Sun and Venus was ♊ (*Gemini*) 15° 36′ 33″; and that the geocentric latitude of Venus was 9′ 44″.9 ſouth.—her horary motion from the Sun 3′ 57″.13 retrograde.—and the angle then formed by the axis of the equator, and the axis of the ecliptic, was 6° 9′ 34″, decreaſing hourly 1 minute of a degree.—By the mean of three good obſervations, the diameter of Venus on the Sun was 58″.

Mr. *Short* made his obſervation at *Savile-Houſe*, in *London*, 30 ſeconds in time weſt from *Greenwich*, in preſence of his royal highneſs the duke of *York*, accompanied by their royal highneſſes prince *William*, prince *Henry*, and prince *Frederick*.—He firſt ſaw Venus on the Sun, through flying-clouds, at 46 minutes 37 ſeconds after 5 o'clock; and at 6 hours 15 minutes 12 ſeconds he meaſured the diameter of Venus 59″.8.—He afterward found it to be 58″.9 when the ſky was more favourable.—And, through a reflecting teleſcope of two feet focus, magnifying 140 times, he found the internal contact of Venus with the Sun's limb to be at 8 hours 18 minutes 21½ ſeconds, apparent time; which, being reduced to the apparent time at *Greenwich*, was 8 hours 18 minutes 51½ ſeconds: ſo that his time of ſeeing the contact was 8½ ſeconds ſooner (in abſolute time) than the inſtant of it's being ſeen at *Greenwich*.

Meſſrs. *Ellicott* and *Dollond* obſerved the internal contact at *Hackney*, and their time of ſeeing it, reduced to the time at *Greenwich*, was at 8 hours 18 minutes 56 ſeconds, which was 4 ſeconds ſooner in abſolute time than the contact was ſeen at *Greenwich*.

Mr. *Canton*, in *Spittle-Square*, *London*, 4′ 11″ weſt of *Greenwich*, (equal to 16 ſeconds 44 thirds of time) meaſured the Sun's diameter 31′ 33″ 24‴, and the diameter of Venus on the Sun 58″; and by obſervation found the apparent time of the internal contact of Venus with the Sun's limb to be at 8 hours 18 minutes 41 ſeconds; which, by reduction, was only 2¼ ſeconds ſhort of the time at the Royal Obſervatory at *Greenwich*.

The Reverend Mr. *Richard Haydon*, at *Leſkeard*, in *Cornwall* (16 minutes 10 ſeconds in time weſt from *London*, as ſtated by Dr. *Lewis*) obſerved the internal contact to be at 8 hours 0 minutes 20 ſeconds, which by reduction was 8 hours 16 minutes 30 ſeconds at *Greenwich*: ſo that he muſt have ſeen

it 2 minutes 30 ſeconds ſooner in abſolute time than it was ſeen at *Greenwich*—a difference by much too great to be occaſioned by the difference of parallaxes. But by a memorandum of Mr. *Haydon*'s ſome years before, it appears that he then ſuppoſed his weſt longitude to be near two minutes more; which brings his time to agree within half a minute of the time at *Greenwich*; to which the parallaxes will very nearly anſwer.

At *Stockholm* Obſervatory, latitude 59° 20′½ north, and longitude 1 hour 12 minutes eaſt from *Greenwich*, the whole of the tranſit was viſible: the total ingreſs was obſerved by Mr. *Wargentin* to be at 3 hours 39 minutes 23 ſeconds in the morning, and the beginning of egreſs at 9 hours 30 minutes 8 ſeconds: ſo that the whole duration between the two internal contacts, as ſeen at that place, was 5 hours 50 minutes 45 ſeconds.

At *Torneo* in *Lapland* (1 hour 27 minutes 28 ſeconds eaſt of *Paris*) Mr. *Hellant*, who is eſteemed a very good obſerver, found the total ingreſs to be at 4 hours 3 minutes 59 ſeconds; and the beginning of egreſs to be 9 hours 54 minutes 8 ſeconds. —So that the whole duration between the two internal contacts was 5 hours 50 minutes 9 ſeconds.

At *Hernoſand*, in *Sweden* (latitude 6° 38′ north, and longitude 1 hour 2 minutes 12 ſeconds eaſt of *Paris*) Mr. *Giſter* obſerved the total ingreſs to be at 3 hours 38 minutes 26 ſeconds; and the beginning of egreſs to be at 9 hours 29 minutes 21 ſeconds.—The duration between theſe two internal contacts 5 hours 50 minutes 56 ſeconds.

Mr. *De la Lande*, at *Paris*, obſerved the beginning of egreſs to be at 8 hours 28 minutes 26 ſeconds apparent time.—But Mr. *Ferner* (who was then at *Conflans*, 14″½ weſt of the Royal Obſervatory at *Paris*) obſerved the beginning of egreſs to be at 8 hours 28 minutes 29 ſeconds true time. The equation, or difference between the true and

apparent

apparent time, was 1 minute 54 ſeconds.—The total ingreſs, being before the Sun roſe, could not be ſeen.

At *Tobolſk*, in *Siberia*, Mr. *Chappe* obſerved the total ingreſs to be at 7 hours 0 minutes 28 ſeconds in the morning, and the beginning of egreſs to be at 49 minutes $20\frac{1}{2}$ ſeconds after 12 at noon.—So that the whole duration of the tranſit between the internal contacts was 5 hours 48 minutes $52\frac{1}{2}$ ſeconds, as ſeen at that place: which was 2 minutes $3\frac{1}{2}$ ſeconds leſs than as ſeen at *Hernoſand* in *Sweden*.

At *Madraſs*, the Reverend Mr. *Hirſt* obſerved the total ingreſs to be at 7 hours 47 minutes 55 ſeconds apparent time in the morning; and the beginning of egreſs at 1 hour 39 minutes 38 ſeconds paſt noon.—The duration between theſe two internal contacts was 5 hours 51 minutes 43 ſeconds.

Profeſſor *Mathenci* at *Bologna* obſerved the beginning of egreſs to be at 9 hours 4 minutes 58 ſeconds.

At *Calcutta* (latitude 22° 30′ north, nearly 92° eaſt longitude from *London*) Mr. *William Magee* obſerved the total ingreſs to be at 8 hours 20 minutes 58 ſeconds in the morning, and the beginning of egreſs to be at 2 hours 11 minutes 34 ſeconds in the afternoon. The duration between the two internal contacts 5 hours 50 minutes 36 ſeconds.

At the *Cape of Good Hope* (1 hour 13 minutes 35 ſeconds eaſt from *Greenwich*) Mr. *Maſon* obſerved the beginning of egreſs to be at 9 hours 39 minutes 50 ſeconds in the morning.

All theſe times are collected from the obſervers' accounts, printed in the Philoſophical Tranſactions for the years 1762 and 1763, in which there are ſeveral other accounts that I have not tranſcribed. —The inſtants of Venus's total exit from the Sun are likewiſe mentioned, but they are here left out, as not of any uſe for finding the Sun's parallax.

Whoever compares theſe times of the internal contacts, as given in by different obſervers, will find

ſuch difference among them, even thoſe which were taken upon the ſame ſpot, as will ſhew, that the inſtant of either contact could not be ſo accurately perceived by the obſervers as Dr. HALLEY thought it could: which probably ariſes from the difference of peoples eyes, and the different magnifying powers of thoſe teleſcopes through which the contacts were ſeen.—If all the obſervers had made uſe of equal magnifying powers, there can be no doubt but that the times would have more nearly coincided: ſince it is plain, that ſuppoſing all their eyes to be equally quick and good, they whoſe teleſcopes magnified moſt, would perceive the point of internal contact ſooneſt, and of the total exit lateſt.

Mr. *Short* has taken an incredible deal of pains in deducing the quantity of the Sun's parallax, from the beſt of thoſe obſervations which were made both in *Britain* and abroad: and finds it to have been 8″.52 on the day of the tranſit, when the Sun was very nearly at his greateſt diſtance from the Earth; and conſequently 8″.65 when the Sun is at his mean diſtance from the Earth.—And indeed, it would be very well worth every curious perſon's while, to purchaſe the ſecond part of Volume LII of the Philoſophical Tranſactions, for the year 1763; even if it contained nothing more than Mr. *Short*'s paper on that ſubject.

The log. ſine (or tangent) of 8″.65 is 5.6219140, which being ſubtracted from the radius 10.0000000, leaves remaining the logarithm 4.3780860, whoſe number is 23882.84; which is the number of ſemidiameters of the Earth that the Sun is diſtant from it.—And this laſt number, 23882.84, being multiplied by 3985, the number of *Engliſh* miles contained in the Earth's ſemidiameter, gives 95,173,117 miles for the Earth's mean diſtance from the Sun.—But becauſe it is impoſſible, from the niceſt obſervations of the Sun's parallax, to be ſure of its true diſtance from the Earth within 100 miles,

miles, we ſhall at preſent, for the ſake of round numbers, ſtate the Earth's mean diſtance from the Sun at 95,173,000 *Engliſh* miles.

And then, from the numbers and analogies in § 11 and 14 of this Diſſertation, we find the mean diſtances of all the reſt of the planets from the Sun in miles to be as follows.—Mercury's diſtance, 36,841,468; Venus's diſtance, 68,891,486; Mars's diſtance, 145,014,148; Jupiter's diſtance, 494,990,976; and Saturn's diſtance, 907,956,130*.

So that, by comparing theſe diſtances with thoſe in the Tables at the end of the chapter on the Solar Syſtem †, it will be found that the dimenſions of the Syſtem are much greater than what was formerly imagined; and conſequently, that the Sun and all the planets (except the Earth) are much larger than as ſtated in that table.

The ſemidiameter of the Earth's annual orbit being equal to the Earth's mean diſtance from the Sun, viz. 95,173,000 miles, the whole diameter thereof is 190,346,000 miles. And ſince the circumference of a circle is to it's diameter as 355 is to 113, the circumference of the Earth's orbit is 597,989,646 miles.

And, as the Earth deſcribes this orbit in 365 days 6 hours (or in 8766 hours) it is plain that it travels at the rate of 68,216.9 miles every hour, and conſequently 1136.9 miles every minute; ſo that it's velocity in it's orbit is at leaſt 142 times as great as the velocity of a cannon-ball, ſuppoſing the ball to move through 8 miles in a minute, which it is found to do very nearly:—and at this rate it would take 22 years 228 days for a cannon-ball to go from the Earth to the Sun.

* When I computed the diſtances in the laſt line of § 13, pag. 106. I had heard that the Sun's parallax was found to be 8″ 69; which occaſions the difference between thoſe diſtances and theſe which ariſe here from the parallax 8″.65, as I found it in the Philoſophical Tranſactions.

† Fronting pag. 40.

On the 3d of *June*, in the year 1769, Venus will again paſs over the Sun's diſc, in ſuch a manner, as to afford a much eaſier and better method of inveſtigating the Sun's parallax than her tranſit in the year 1761 has done.—But no part of *Britain* will be proper for obſerving that tranſit, ſo as to deduce any thing with reſpect to the Sun's parallax from it, becauſe it will begin but a little before ſun-ſet, and will be quite over before 2 o'clock next morning.—The apparent time of conjunction of the Sun and Venus, according to Dr. HALLEY's Tables, will be at 13 minutes paſt 10 o'clock at night at *London*; at which time, the geocentric latitude of Venus will be full 10 minutes of a degree north from the Sun's center:—and therefore, as ſeen from the northern parts of the Earth, Venus will be conſiderably depreſſed by a parallax of latitude on the Sun's diſc; on which account, the viſible duration of the tranſit will be lengthened: and in the ſouthern parts of the Earth ſhe will be elevated by a parallax of latitude on the Sun, which will ſhorten the viſible duration of the tranſit, with reſpect to it's duration as ſuppoſed to be ſeen from the Earth's center; to both which affections of duration the parallaxes of longitude will alſo conſpire.—So that every advantage which Dr. HALLEY expected from the late tranſit will be found in this, without the leaſt difficulty or embarraſſment.—It is therefore to be hoped, that neither coſt nor labour will be ſpared in duly obſerving this tranſit; eſpecially as there will not be ſuch another opportunity again in leſs than 105 years afterward.

The moſt proper places for obſerving the tranſit in the year 1769 is in the northern parts of *Lapland*, and the *Solomon Iſles* in the great *South-Sea*; at the former of which, the viſible duration between the two internal contacts will be at leaſt 22 minutes greater than at the latter, even though the

Sun's

Sun's parallax ſhould not be quite 9″——If it be 9″ (which is the quantity I had aſſumed in a delineation of this tranſit, which I gave in to the Royal Society before I had heard what Mr. *Short* had made it from the obſervations on the late tranſit) the difference of the viſible durations, as ſeen in *Lapland* and in the *Solomon Iſles*, will be as expreſſed in that delineation; and if the Sun's parallax be leſs than 9″ (as I now have very good reaſon to believe it is) the difference of durations will be leſs accordingly.

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# ASTRONOMY

EXPLAINED UPON

Sir ISAAC NEWTON's PRINCIPLES,

And made eaſy to thoſe who have not ſtudied

MATHEMATICS.

To which are added,

A PLAIN METHOD

OF FINDING

The DISTANCES of all the PLANETS from the SUN, by the TRANSIT of VENUS over the SUN's DISC, in the Year 1761.

An Account of Mr. HORROX's Obſervation of the TRANSIT of VENUS in the Year 1639:

AND,

Of the DISTANCES of all the PLANETS from the SUN, as deduced from OBSERVATIONS of the TRANSIT in the Year 1761.

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By JAMES FERGUSON, *F.R.S.*

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HEB. xi. 3. *The Worlds were framed by the Word of* GOD.
JOB xxvi. 7. *He hangeth the Earth upon nothing.*
——— 13. *By his Spirit he hath garniſhed the Heavens.*

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MDCCLXX.

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